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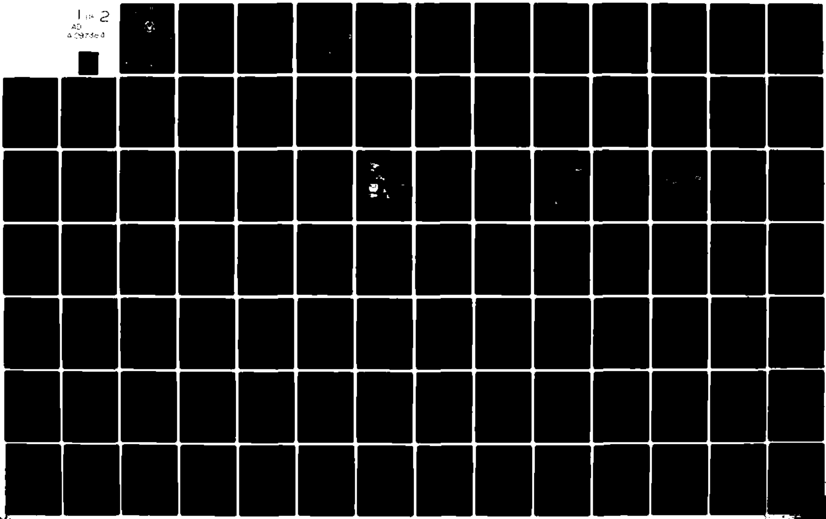

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Monterey, California

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THESIS

USE OF THE TI 59 WITH APPLICATIONS TO PROBABILITY AND STATISTICAL ANALYSIS

by

George Russell Nelson

Edgar Emmett Stanton, III

December 1980

Thesis Advisor: P. W. Zehna

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The second example illustrates a TI 59 program which is designed to analyze sample data. The data used for this illustration were gathered by the authors in an experiment which encompassed the testing of thirty-six male subjects to determine the extent to which their training routines influenced their strength, endurance, and cardiovascular fitness. The third example involves the use of an ANOVA routine and Scheffe's multiple contrasts to demonstrate how the TI 59 may be used to facilitate statistical inferences. The fitness data are also used for this purpose. The intent throughout the thesis is to exemplify the capabilities of the TI 59 as a viable, real world analytical tool rather than emphasize particular results of the simulation or the experiment.

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Use of the TI 59 with Applications

to Probability and Statistical Analysis

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

This thesis demonstrates through three comprehensive examples, the capabilities of the TI 59 programmable hand-held calculator as an analytical tool. One example is a probability application while the other two examples entail use of the TI 59 in statistical inference and data analysis. The probability example involves the use of the Monte Carlo technique to simulate stochastically the detection, identification and engagement of a cruise missile by an Improved Hawk Air Defense Battery. The second example illustrates a TI 59 program which is designed to analyze sample data. The data used for this illustration were gathered by the authors in an experiment which encompassed the testing of thirty-six male subjects to determine the extent to which their training routines influenced their strength, endurance, and cardiovascular fitness. The third example involves the use of an ANOVA routine and Scheffe's multiple contrasts to demonstrate how the TI 59 may be used to facilitate statistical inferences. The fitness data are also used for this purpose. The intent throughout the thesis is to exemplify the capabilities of the TI 59 as a viable, real world analytical tool rather than emphasize particular results of the simulation or the experiment.

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I. INTRODUCTION

The intent of this thesis is do demonstrate through three comprehensive examples, the tremendous capabilities of the TI 59 programmable hand-held calculator. One of the examples is a probability application while the other two entail use of the TI 59 in statistical inference and data analysis.

The example chosen to illustrate an application to probability theory is a combat simulation model. The model involves use of the Monte Carlo technique to simulate stochastically detection, identification, and engagement of a cruise missile by an Improved Hawk Air Defense Battery. Chapter III discusses the combat model and the TI 59 simulation in detail. Chapter II addresses briefly the Monte Carlo technique, combat modeling in general, and the TI 59 random number generator in order that the reader may better understand the combat model discussed in Chapter III.

Two examples are provided for statistical applications of the calculator. These involve the analysis of data gathered by the authors in a physical fitness experiment. The experiment, discussed in detail in Chapter IV, involved the testing of thirty-six male subjects who were divided into six categories based on their training routine, to determine whether the subjects' training program did in fact influence their physical fitness. Chapter IV describes the fitness experiment in terms of its scope, design and scoring methodology. Chapter IV also discusses a TI 59 program which computes measures of central tendency and spread and then illustrates the use of the program with the fitness data.

Chapter V describes a TI 59 program for analysis of variance and then demonstrates how the program may be used with fitness data to make statistical inferences.

Throughout the thesis, it is assumed that the reader is generally familiar with programming techniques for the TI 59 hand-held calculator. Subroutines, labels, flags, data registers, and program steps are discussed in each of the ensuing chapters where the intent is to illustrate how the features of the calculator may be exploited to facilitate statistical analysis or simulation. Reference 12 discusses programming techniques for the TI 59. The TI 59 has one particular feature which makes it much more than a calculator. Specifically the capacity to use subroutines provides a analytical tool more like a minicomputer than a calculator. The three programs discussed in the succeeding chapters use subroutines extensively to illustrate this powerful capability.

Finally, while a few of the referenced tables and charts of this thesis are positioned close to comments discussing their purpose, most are to be found at the conclusion of each chapter or in the appendices.

II. PROBABILITY

The intention of the authors was to begin this chapter discussion with a definition of probability theory, that branch of mathematics generally believed to have been founded by a Swiss mathematician named Jacques Bernoulli. However, research has revealed that there is some discussion as to the true meaning of probability theory and that among mathematicians there appear to be those who view probability as a state of the universe while others consider probability a state of belief. To compound this situation furthermore, there appear to be differing definitions of probability within each group. Indeed, all attempts to define probability directly have failed to meet with success. Instead, probability has been axiomitized, much like geometry, so that a set of consistency rules or axioms established by A. Kolmogorov are now generally accepted by the scientific community. These axioms allow a great deal of freedom in the assignment of probabilities for any particular model and at the same time force any such assignment to be consistent with any other. Moreover, the theorems of that theory then become universally true statements for any such assignment. In this system, events are defined as sets in a specified sample space. With those guidelines as a background, probability theory can be used to make intelligent predictions and decisions if we know what events are possible and how probable are the various events. After a little thought it becomes immediately apparent that the immense power of such a tool as probability theory is limited in use only by one's imagination and ingenuity. This research is an effort to use probability theory in the construction of a probabilistic combat simulation on the Texas Instruments programmable 59 calculator (TI 59). Because the simulation developed includes a number of the many chance elements involved in most combat situations, a discussion of the Monte Carlo technique and random number generation on the TI 59 follows. A brief disucssion of combat model simulations concludes this chapter.

A. MONTE CARLO TECHNIQUE

Systems that exhibit stochastic elements in their behavior can be simulated with the aid of the technique called Monte Carlo (named after the famous gambling resort town of Monaco). This technique involves sampling from those known probability distributions that represent each of the actual chance processes included in the system under study [Ref. 8]. By completing a system simulation run many times while keeping the non-stochastic inputs constant but allowing the chance elements to fluctuate according to their known probability distributions, a statistical average for run results can be determined.

Turban and Meredith [Ref. 8] have listed the steps necessary in building a Monte Carlo simulation as follows:

"1. Describe the system and obtain the probability distributions of the relevant probabilistic elements of the system.
2. Define the appropriate measure(s) of performance.
3. Construct cumulative probability distributions for each of the stochastic elements.
4. Assign representative numbers in correspondence with the cumulative probability distributions.
5. Generate a random number for each of the independent stochastic elements and . . . (determine) the measure of system performance.
6. Repeat step five until the measure of system performance stabilizes."

Thus the distinguishing feature of the Monte Carlo method is the repetitive execution of an established experiment or simulation involving randomness.

While electronic digital computers themselves are not necessary for the execution of simulations, they do offer tremendous speed and consistency of conditions for such models. Thus the computer is ideally suited to perform the large number of repetitions required by Monte Carlo but the matter of randomness presents a problem. For the Monte Carlo technique described above the necessity of a truly random number is essential. However Kovach [Ref. 6] notes that:

> "Strictly speaking, the random number exists only as the result of a random process."

While computers, to include the TI 59, do possess the capacity to continuously generate random numbers as they are needed, these numbers are subject to the limitations of the computer and are not truly the result of a random process and hence are often described as pseudo-random.

B. TI 59 RANDOM NUMBER GENERATOR

R.F. Barton [Ref. 4] describes simulation as follows:

> "Simulation is simply the dynamic execution or manipulation of a model of an object system for some purpose.
>
> Simulation is a case-by-case method for studying object systems. Each case might be either a single trial or an entire run. In either view, outputs may differ trial to trial and run to run."

The object system is that system under study in the simulation.

The TI 59 in its capacity as an electronic computer provides the user with the means of developing and executing stochastic and nonstochastic simulations.

Barton continues [Ref. 4] :

" A stochastic simulation is one in which differing outputs trial to trial can be obtained without changing the inputs (ignoring random numbers as inputs). Specifically, this means that identical parameters, starting conditions, and input time path values produce varying outputs trial to trial and run to run.

A nonstochastic simulation is one in which the inputs or the model must be changed to obtain changed outputs. This means that identical model operations, parameters, starting conditions, and input time path values will produce identical outputs run to run. "

There are inputs common to both of these simulation types. However, as alluded to above, there are also special inputs that are needed to represent the chance processes or stochastic events found only within a stochastic simulation. These special inputs are random numbers.

The characteristic of random numbers that makes them different from all other numbers is the fact that the knowledge of any future random number cannot be enhanced by the knowledge of any past, present, or other future random number.

The TI 59 with its master library module solid state software program ML-15, a random number generator, can generate sequences of uniformly or normally distributed random numbers independent of a simulation program or within such a program.

Kovach states [Ref. 6] :

"(Random) numbers generated by the computer are sometimes-called pseudo-random because they are subject to the limitations of the computer. In a list of truly random numbers, for example, one would expect to find numbers containing more digits than can be obtained in a computer."

Random numbers produced by the TI 59 ML-15 program are generated by a mathematical formula. Given an initial seed number by the user, this program will always produce the same list of pseudo-random numbers. Thus if repeatedly initialized with the same seed number the forthcoming random numbers would be known and randomness would not exist. That is, every future random number could be predicted. Hence, the randomness of the numbers produced by the ML-15 program are as dependent upon the user as the mathematical formula of the program itself. It is therefore incumbent upon the routine user of the ML-15 program to vary the seed number used within denoted limits to insure genuine pseudo-random numbers.

The TI 59 ML-15 random number generator program is listed in Table 2-1. User instructions for the ML-15 program [Ref. 11] are listed in Table 2-2. Data register contents are listed in Table 2-3.

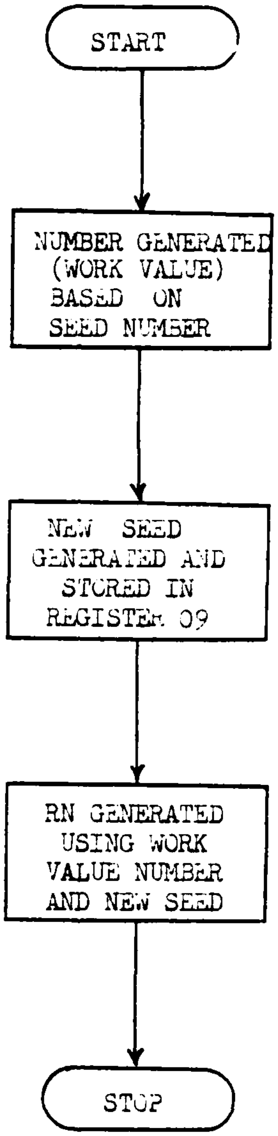
While the program does provide the option of generating uniform numbers for ranges other than 0-1 and also provides statistical data for the random numbers generated, only the generation of the uniform, range 0-1, and the normal random numbers will be discussed further.

1. Uniform Random Number Generator

A flowchart of the uniform random number generator, range 0-1, is displayed in figure 2-1. Program steps 000 through 054 contain the following mathematical formula, called the linear congruential method [Ref. 11], for the generation of these numbers. (Throughout this thesis an asterisk is used to indicate multiplication.)

((24298 * SEED + 99991) ÷ 199017 STO 07)

A work value is the result of the above operation. This result remains in the display register. The value 199017 is stored in data register 07, an ML-15 work register.



TI 59 Uniform Random Number Generator

FIGURE 2-1

Calculation continues.

(INV INT * RCL 07) STO 09

The integer portion of the number resulting from the previous operation is discarded, then the remaining fractional portion is multiplied by 199017 which was stored in data register 07. This product then is stored in data register 09 and becomes the seed for the next random number calculation. Calculation continues.

((RCL 09 ÷ RCL 07) * 5 INV 2nd log)

Now the new seed is divided by the number 199017 which was stored in data register 07 during the first operation. This quotient is then multiplied by the common antilogarithm of 5 to complete the step. Calculation continues.

(INT ÷ 5 INV log)

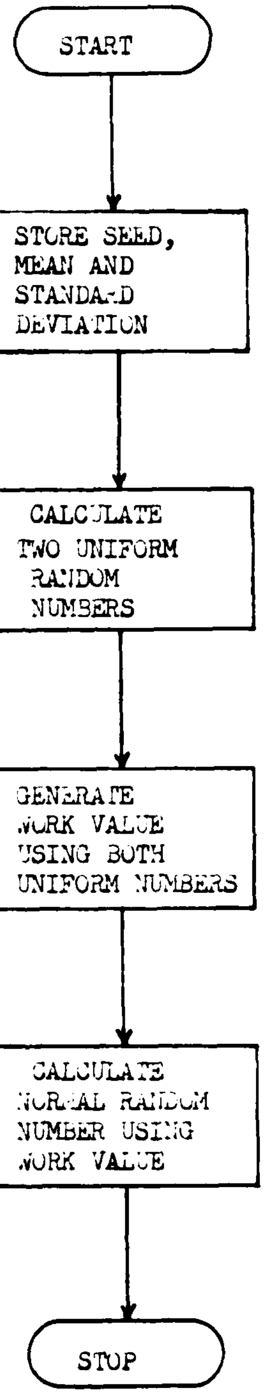
The fractional portion of the previous numerical operation is discarded and the result divided by the common antilogarithm of 5. This quotient is then displayed as the uniform random number, range 0-1.

2. Normal Random Number Generator

A flowchart of the normal random number generator is displayed in figure 2-2. Program steps 069 through 135 contain the following mathematical formula, called the direct method [Ref. 1] for the generation of these numbers.

(seed STO 09)
(mean STO 10)
(standard deviation STO 11)

Following program initialization, three data values are entered and stored in data registers 09, 10, 11. The seed number, the desired normal distribution mean (mu) and the desired normal standard deviation



TI 59 Normal Random Number Generator

FIGURE 2-2

(sigma) are stored in these registers as listed respectively. The seed value is limited as noted in the TI user instructions, table 2-2.

(SBR DMS STO 08 SBR DMS)

Initially the program calls the previously discussed uniform random number generator to produce such a number and then stores it in data register 08. The uniform generator is called again to produce another uniform random number which remains in the display register for manipulation and is denoted RN. Calculation continues.

((RN * 2 * π) COS) * ((RCL 08 LnX) * (-2)

The uniform random number in the display is next multiplied by two pi. The cosine of this product is then calculated. The resulting value is multiplied by the product of the natural logarithm of the first uniform random number (generated early and stored in data register 08) multiplied by negative two. This product remains in the display register for manipulation. Calculation continues.

($\sqrt{}$ * RCL 11) + RCL 10

The squareroot of the previous operation end value is multiplied by the desired standard deviation. Finally, this product is added to the desired mean, resulting in the generated normal random number. Seed manipulation for the generation of successive normal random numbers is completed during the SBR D.MS portion of the normal generation program.

3. <u>SBR 2nd D.MS</u>

The TI 59 ML 15 program does compile statistical data to allow computation of the mean and standard deviation of the pseudo-random numbers generated when using the normal distribution routine and the uniform distribution routine over ranges other than 0-1. However, these data are not compiled when SBR 2nd D.MS sequence is executed to produce uniformly distributed numbers over the 0-1 range. Data registers one through eleven are used by the ML-15 program to compile and compute these statistics. Hence, if this program is called to produce normal random numbers within a larger program, such as a simulation, the use of these eleven data registers must be forgone. Yet, if the ML-15 program is called only to produce uniform random numbers over the range 0-1, only data registers seven and nine are used by ML-15, freeing nine registers for other use. This aspect of the TI 59 ML-15 program must be carefully considered when utilizing it is as a subroutine within another program.

C. COMBAT MODELS

Today there are considered to be three types of combat models in use; war games, pure simulations and analytical models. War games are models and games [Ref. 2] :

> " . . . in which individuals simulating decision makers in real life use their judgement to perform the decision functions in the model."

A war game may include automation to assist in the processing of data and the generation of random numbers to determine the outcome of certain chance events. A war game may also be a player-assisted simulation where players provide input to a computer model based on output (readouts) during a simulated battle. In comparison with the other models, war games appear to be more realistic, involve greater player interaction, are less automated, require much more time to run, more resources and involve a smaller degree of abstraction.

Simulation combat models are models [Ref. 2] :

". . . which run completely without human intervention. In this type of model events in the different combat processes are based on predetermined rules which are programmed into the automated evaluation procedure."

Combat models of this type generally contain a significant number of the important stochastic elements of combat in an attempt to simulate real battle. These models use probability distributions for the many chance input variables and produce probability distributions as results. They utilize the Monte Carlo technique, repeatedly sampling all input distributions in the programmed sequence to produce a distribution of probable battle results for each set of input data.

Analytical models are models [Ref. 2] :

" . . . comprised of sets of mathematical equations as models of all the basic events and activities in the process being described and an overall assumed mathematical structure of the process into which the event or activity descriptions are integrated. "

While analytical models are the most time efficient they are also the most abstract and difficult to understand. As with the pure simulation, there is no human intervention when an analytical model is used.

All three models represent abstractions of the real world. The models themselves can be observed more conveniently than the real world and theories about the real world can be developed by studying the results of these models. Subsequently, these theories can be used to make predictions about real world events.

Each model type has strengths and limitations, some noted above and others listed in table 2-4 [Ref. 2] .

1. Pure Combat Simulations

Pure combat simulations are normally viewed as production tools, using Monte Carlo techniques to obtain results enabling the prediction of future system performance. But because the real world is so complex and interactive, attempts to model every detail of a large system in a pure simulation and to include every element that may influence the system can result in simulations so large and so complex that they are understood only by their developers and not by other users or decision makers. To avoid this complex dilemma, analytical models can be used to represent elements of the system being modeled instead of simulating the element itself and its inherent stochastic processes with every trial. This technique has been followed to some degree in the pure simulation model presented in Chapter III where the calculation of detection probability is an analytical model with results based on target range.

It should be noted that few, if any, simulation models ever completely include all those elements and events that affect the system(s) under study. Reference 2 points out that:

> ". . . a model is always incomplete, with only those aspects represented that we believe we know well enough to model and that we consider important in the issues to be examined with the model. Obviously, models tend to be as simple and concise as our knowledge of the activity warrants."

This is reflected in the model presented in Chapter III. While all the factors affecting system performance have not been directly simulated they are included either as analytical models or as given in the scenario.

Finally, a point to be stressed is that simulations need not be large to be useful, nor require the use of a large electronic digital computer to be credible. Using large computers for large problems and small computers for small problems is a rule of thumb that may overstate the case but certainly does not exaggerate it. Use of the TI 59 as a computer to tackle the problem set forth in Chapter III is an example of matching the problem to the computing power required. It is also an excellent example of the computing power of the TI 59.

000	76	LBL
001	88	DMS
002	53	(
003	53	(
004	02	2
005	04	4
006	02	2
007	09	9
008	08	8
009	65	×
010	43	RCL
011	09	09
012	85	+
013	09	9
014	09	9
015	09	9
016	09	9
017	01	1
018	54	)
019	55	÷
020	01	1
021	09	9
022	09	9
023	00	0
024	01	1
025	07	7
026	42	STO
027	07	07
028	54	)
029	53	(
030	53	(
031	53	(
032	22	INV
033	59	INT
034	65	×
035	43	RCL
036	07	07
037	54	)
038	42	STO
039	09	09
040	55	÷

TI 59 ML-15

Program

TABLE 2-1.1

041	43	RCL
042	07	07
043	65	×
044	05	5
045	22	INV
046	28	LOG
047	54	)
048	59	INT
049	55	÷
050	05	5
051	22	INV
052	28	LOG
053	54	)
054	92	RTN
055	76	LBL
056	13	C
057	71	SBR
058	88	DMS
059	53	(
060	24	CE
061	65	×
062	53	(
063	43	RCL
064	11	11
065	75	-
066	43	RCL
067	10	10
068	54	)
069	76	LBL
070	37	P/R
071	85	+
072	43	RCL
073	10	10
074	54	)
075	42	STO
076	07	07
077	78	Σ+
078	43	RCL
079	07	07
080	92	RTN

TABLE 2-1.2

081	76	LBL
082	18	C'
083	70	RAD
084	71	SBR
085	88	DMS
086	42	STO
087	08	08
088	71	SBR
089	88	DMS
090	53	(
091	53	(
092	24	CE
093	65	×
094	02	2
095	65	×
096	89	π
097	54	)
098	39	COS
099	65	×
100	53	(
101	43	RCL
102	08	08
103	23	LNX
104	65	×
105	02	2
106	94	+/-
107	54	)
108	34	√X
109	65	×
110	43	RCL
111	11	11
112	61	GTO
113	37	P R
114	76	LBL
115	10	E'
116	36	PGM
117	01	01
118	71	SBR
119	25	CLR
120	92	RTN

TABLE 2-1.3

121	76	LBL
122	15	E
123	42	STO
124	09	09
125	92	RTN
126	76	LBL
127	11	A
128	42	STO
129	10	10
130	92	RTN
131	76	LBL
132	12	B
133	42	STO
134	11	11
135	92	RTN
136	00	0
137	00	0
138	00	0
139	00	0
140	00	0

TABLE 2-1.4

TI 59 PROGRAM ML-15

USER INSTRUCTIONS

(MASTER LIBRARY MODULE)

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	SELECT PROGRAM		2d PGM 15	
2	INITIALIZE		2d E'	0
3	ENTER RANDOM NUMBER SEED (0 ≤ SEED ≤ 199017)	SEED	E	SEED
	FOR NORMAL DISTRIBUTION			
4	ENTER DESIRED MEAN	$\bar{x}$	A	
5	ENTER DESIRED STANDARD DEVIATION	σ	B	
6	GENERATE RANDOM NUMBER (REPEAT AS NEEDED)		2d C'	RANDOM NUMBER
	FOR UNIFORM DISTRIBUTION RANGE (0, 1)			
7	GENERATE RANDOM NUMBER (REPEAT AS NEEDED)		SBR 2d D.MS	RANDOM NUMBER

TABLE 2-2

TI 59 PROGRAM ML-15

DATA REGISTER CONTENTS

REGISTERS:

R_{00}	—
R_{01}	Σy
R_{02}	Σy^2
R_{03}	N
R_{04}	Σx^2
R_{05}	Σx
R_{06}	Σxy
R_{07}	WORK REGISTER
R_{08}	WORK REGISTER
R_{09}	SEED
R_{10}	A, $\bar{x}$
R_{11}	B, σ

TABLE 2-3

War Games	Simulations
Intelligent play of decision maker.	Stylized decision routines, usually fixed throughout game.
Intelligent use of intelligence.	Very limited use of intelligence.
Can plan engagement and moves in advance.	Very limited planning horizon.
Adapts maneuver to situation.	Very limited adapted maneuver routines.
Can play many tactical situations (employment, penetration, etc.).	Usually stylized maneuver, limited change in formations.
Insight is gained by understanding the particular rationale used in the decision process in single situations analyzed.	Insight is gained by repeating the analysis in many situations using different values for key parameters.
Controller determines existence of engagement and pace of play.	Predetermined scenarios and engagement rules -- combat very intense.
Very slow and costly in resources.	Faster to run after completely developed.
Very few situations can be examined.	Many situations can be played and the sensitivity of key variables can be tested.
Greatest visibility for the user.	
Can include direct involvement by user.	

[Reference 1, FM 44-90, Headquarters Department of the Army, 1977]

TABLE 2-4

III. COMBAT SIMULATION USING TI 59

This is a probabilistic duel simulation model, a pure simulation of a combat air battle, designed to reflect the characteristics of the Improved HAWK air defense artillery system (battery) in the manual mode under attack by a single cruise missile of sustained altitude, speed and direction.

The program scenario and engagement rules are predetermined with no user input once the simulation run has begun. Insight may be gained and the sensitivity of key variables tested dependent upon the use of different values entered by the user for these variables during program initialization. (Variables listed under E below.)

The model provides IHAWK system status, target engagement events and battle results as they are determined/occur. Only two battle results are possible: a "KILL" of the cruise missile or a unit "PENETRATION" by the cruise missile.

Given the operational ready rates of the major subsystems of the IHAWK system, the P_{ssk} (probability of single shot kill) and the mean and standard deviation of lock-on-to-target times, the model samples from the uniform and normal distribution to determine system status, IHAWK missile kill or no kill and lock-on times. Target detection is modeled as a function of target range and is represented as a linear relationship in the simulation.

This simulation was developed to exhibit the computing power of the TI 59 and to determine if one parameter under the control of the IHAWK battery commander could significantly affect air battle results. This parameter was the tracking radar "lock-on-to-target" time which is a function of operator training given (1) a manual mode operation, and (2) perfect equipment. The sensitivity of battle results to varying lock-on times is listed under F below.

A. IHAWK SYSTEM

To be effective, an air defense system must be able to detect, identify, engage and destroy an airborne target. The IHAWK system can engage and destroy a full spectrum of threat aircraft and missiles operating throughout a wide range of tactical speeds and altitudes. It can engage a multiple target threat as well as single targets. The system is effective from ground level up to altitudes of about 48000 feet and out to ranges of about 40 kilometers. The system can operate at night, under all conditions of weather and reduced visibility. It can function effectively in an ECM (electronic countermeasures) environment and is mobile using organic unit vehicles or helicopters [Ref. 1]. However, some adverse weather and heavy ECM may diminish some system capabilities. This simulation does not model:
(1) weather
(2) detection ECM
(3) visibility
(4) system mobility

1. Detection

Target detection is accomplished by either the improved pulse acquisition radar (IPAR) or the improved continuous wave acquisition radar (ICWAR), or both. The IPAR can detect low to medium altitude targets out to ranges in excess of 100 kilometers while the ICWAR can detect targets at very low altitudes with ranges in excess of 60

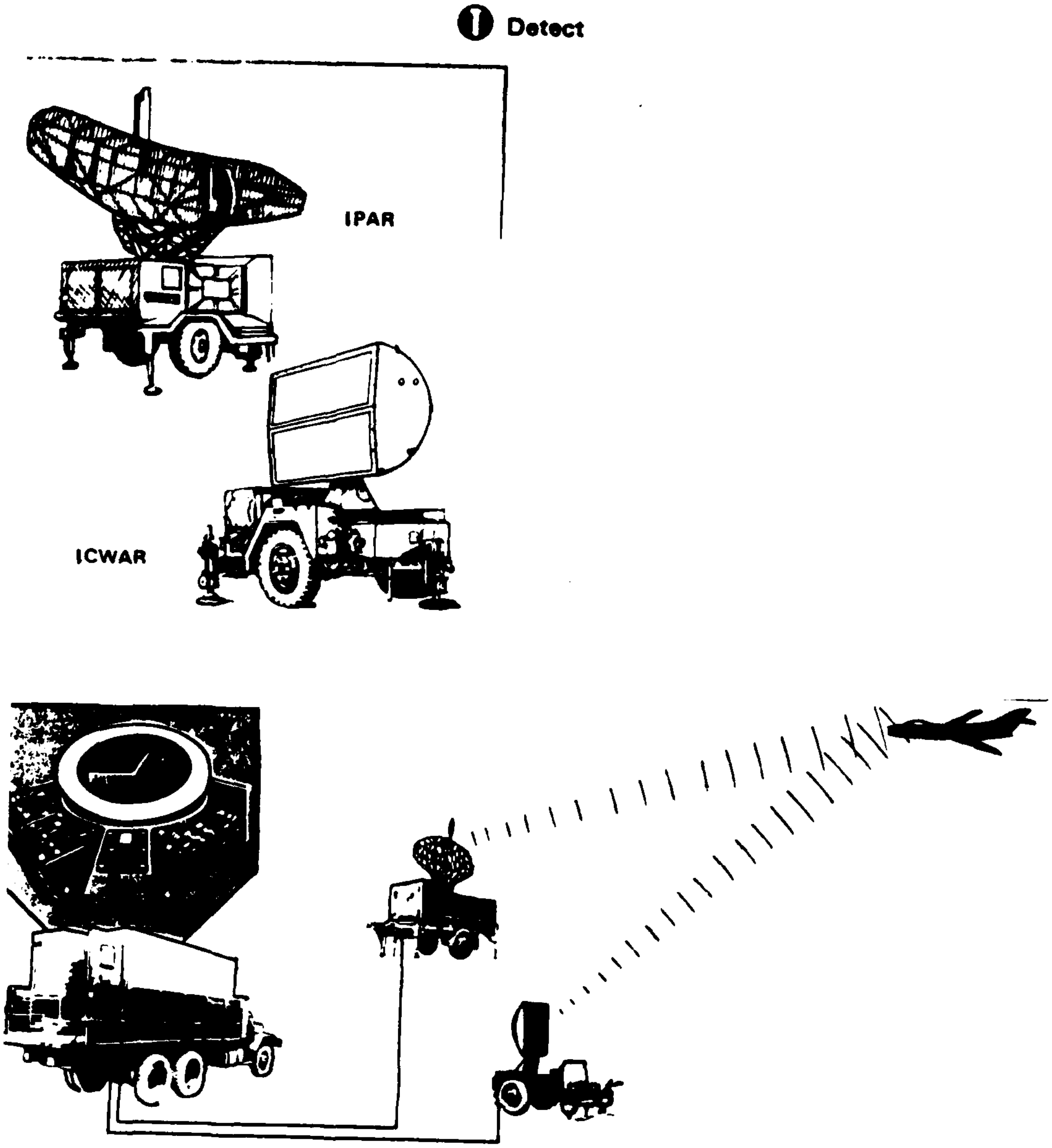


Figure 3-1

kilometers. Operating on the doppler principle, the ICWAR sees only very low moving objects and not stationary objects on the ground. Detection may be reduced if terrain features such as hills, trees and buildings mask the radar's view of the approaching target. Even with completely level terrain, the earth's curvature causes a reduction in the detection and tracking ranges of the system against very low-altitude targets. Also, evasive maneuvers by threat targets may reduce the detection and tracking ranges and increase system response time, thereby reducing the effective or intercept range. This simulation does not model:

(1) terrain features
(2) curvature of the earth
(3) evasive action by targets
(4) pulse detection or continuous wave detection per se

This model assumes:

(1) clear weather
(2) no detection electronic countermeasures
(3) line of sight (LOS) exists between radar and target
(4) flat desert terrain
(5) nonmaneuvering target
(6) only one attacking target exists
(7) target is a cruise missile of constant speed and constant altitude
(8) detection is a function of target range

The probability of detection is modeled during each sweep of the radar as a linear function of target range from the battery as follows:

For the IPAR the $P_{DET} = \left[(-.25 \div 65) * \text{Target Range}\right] + 1.0$

For the ICWAR the $P_{DET} = \left[(-.5 \div 65) * \text{Target Range}\right] + 1.0$

The probability of detection is calculated every three seconds of simulated time. This is based on the radar rotation rate of 20 revolutions per minute. That is, every three seconds each radar takes a 360 degree glimpse of the horizon. The radars are slaved to each other and rotate in synchronization. Additionally, the IPAR is modeled to detect only targets from 5000 to 40000 feet in altitude while the ICWAR detects targets from 1 to 8000 feet in altitude. Thus the battery's very low and low to medium detection capability is dependent upon the operational status of these radars as noted. Targets above 40,000 feet cannot be detected in this simulation. The operational ready rates of these two radars has been arbitrarily set at .65 (ICWAR) and .95 (IPAR).

2. Identification

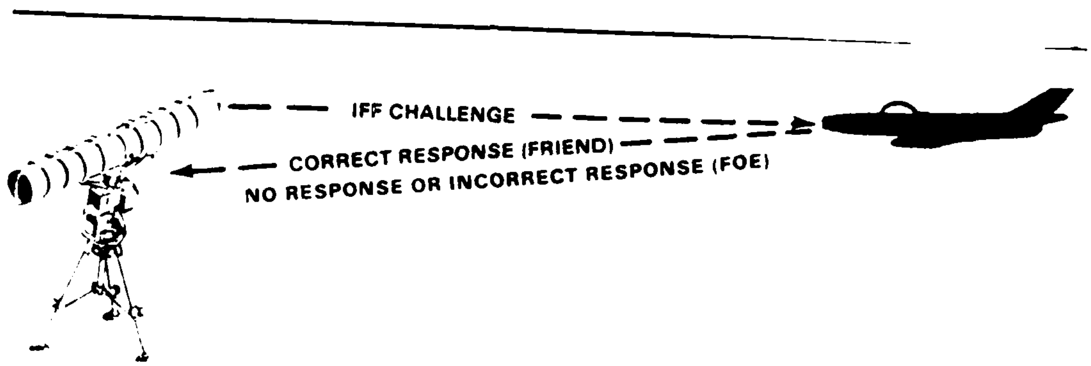
Identification of any potential target is accomplished by means of the identification, friend or foe (IFF), equipment of the IHAWK system and/or other established hostile criteria. If the target cannot be positively identified in this simulation because of a nonoperational IFF, the target speed and altitude is checked to determine target status (foe or not foe). That is, if the IFF is nonoperational and if the target is below 5000 feet altitude and greater than 550 KMPH in speed, it is identified as a foe; otherwise, it is not a foe.

This model assumes: (1) once identified as a friend, always a friend,
(2) once identified as a foe, always a foe.

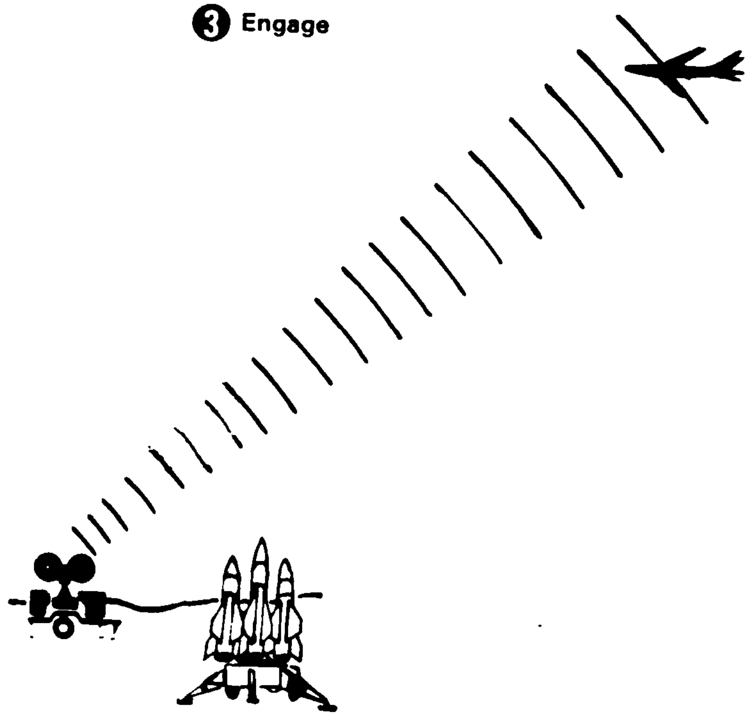
The operational ready rate of the IFF has been arbitrarily set at 95 percent. This model does play IFF accuracy to the degree that an operational IFF will be in error two percent of the time. That is, a foe will be shown to be a friend two percent of the time. This model assumes operational IFF accuracy to be 98 percent.

❷ Identify

Figure 3-2



❸ Engage



3. Engagement/Destruction

The IHAWK battery has two firing sections, each of which contains a target tracking radar which is called an improved high powered illuminating radar (IHIPIR), and three launchers with three missiles each. If a potential target is determined to be a foe, it is assigned to one or both of these firing sections. The tracking radar of these sections, under the control of a fire control operator (enlisted personnel), attempts to lock-on to the approaching hostile target. The operator directs the automatic box search of the radar in the azimuth and expected elevation of the target in attempting this target lock. The operator's ability to achieve a target lock is a function of his training given the condition mentioned above. The time that elapses in attempting this target lock is extremely important. Target engagement cannot continue without target lock and the longer it takes to achieve target lock the closer the target moves toward the battery, reducing the intercept range. Tracking radar lock-on times are assumed to be normally distributed. After target lock has been achieved and the target is in range, one or two missiles are fired on order from the unit tactical control officer in a battery control van. Engagement is continued until the target is destroyed or until engagement is no longer possible. This simulation models each firing section as an entity. After a target has been declared a foe and assigned to one or both firing sections, this model simulates the target lock-on time by utilizing the TI 59 normal random number generator based on a normal mu and sigma input by the user during initialization.

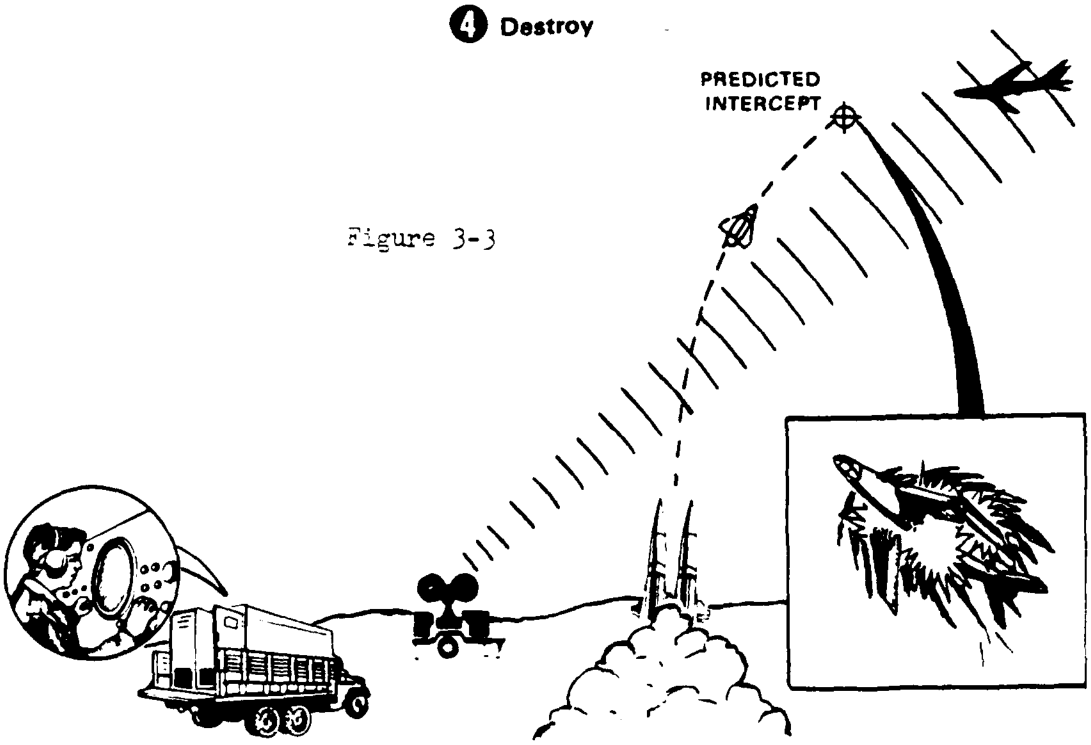
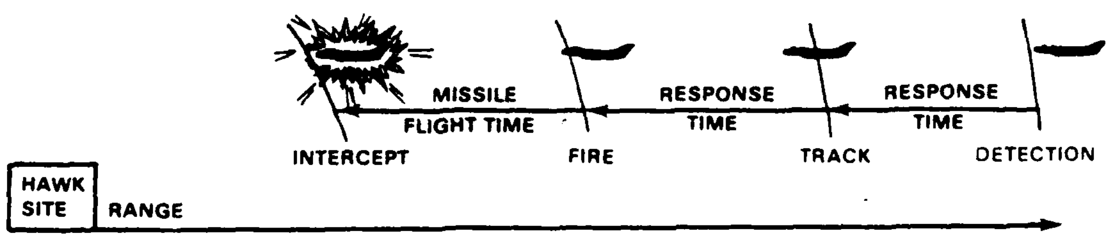


Figure 3-3



The range at intercept is determined by the range at which detection and tracking (lock-on by the HIPIR) occur and on system response time.

In this model, targets are engaged that are:

(1) declared to be foe
(2) less than 40 KM from the battery
(3) greater than 8 KM from the battery

This model assumes:

(1) two independent firing sections
(2) salvo fire occurs if both sections are operational and shoot-look-shoot if only one section is operational
(3) firing continues until kill or penetration
(4) penetration means that the target is 8 KM or less from the battery
(5) lock-on-to-target time is a function of operator training and is normally distributed
(6) P_{ssk} = .75 (arbitrarily set)

The operational ready rate of each firing section has been arbitrarily set at 75 percent.

4. Target

The target for this model is assumed to be a hostile cruise missile that flies straight in toward the battery at a constant speed and altitude as established by the user during initialization. The initial range of the target is also a user input. The lethality of the missile warhead is assumed to be such that any successful penetration by the missile to within 8 KM or less of the battery before destruction is considered a total penetration of the battery defended area. Therefore, the target must be destroyed before 8 KM to score a kill. Additionally, a target will not be engaged after detection until it is less than 40 KM from the battery and no further missiles will be fired at the target once it is within 8 KM of the battery. The target speed has a lower bound of 100 KMPH but no upper bound. Only targets between 1 and 40000 feet in altitude can be detected and are thus the altitude bounds. Finally, all targets are hostile and will be engaged unless erroneously identified as friendly or not foe, resulting in a free penetration.

5. Time

This simulation is a time step model, updating all battery events and functions every three seconds of simulated time. This three-second interval stems from the rotation rate of the detection radars, 20 revolutions per minute or one complete rotation (scan of the horizon) every three seconds.

B. MACRO FLOW CHART

The enclosed macro flow chart, figure 3-4, depicts the general flow of the simulation logic from start to either penetration or kill.

First the model determines if a detection capability exists. This could be one or both of the detection radars. Using the internal random number generator of the TI 59 for a 0-1 uniform distribution, two random numbers are drawn and compared with the detection radar operational ready rates. If the random number is less than the rate, the radar is operational; otherwise, it is nonoperational. If no detection capability exists the simulation is terminated by a penetration of the defended area by the target.

Detection of the target is based partly on the formulas set forth above and results of the 0-1 range uniform random number generator. The probability of detection is based on the range of the approaching target and is recalculated every three seconds. The probability of detection for each radar is compared with a generated random number between 0 and 1. If the random number is less than the probability

MACRO FLOWCHART

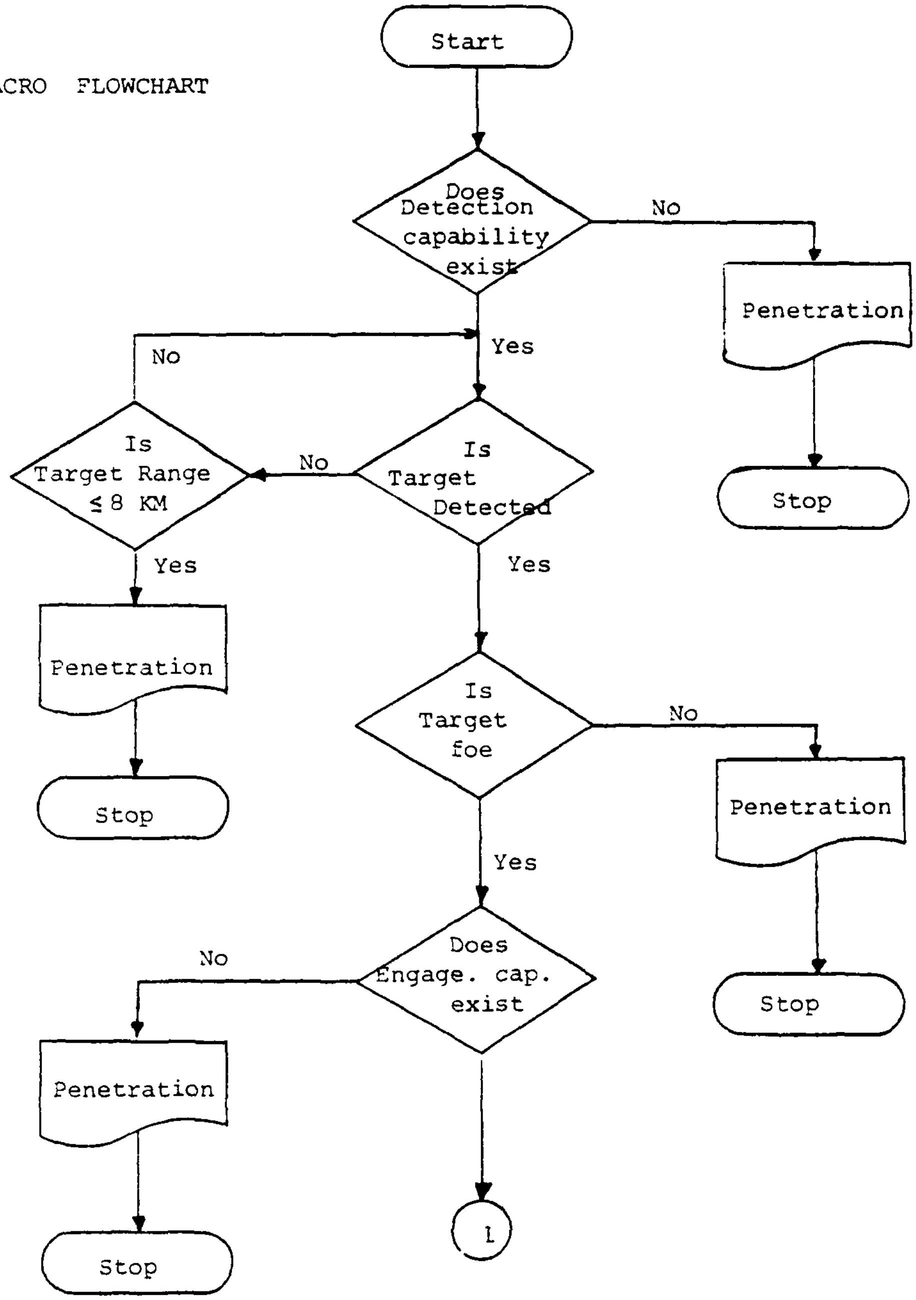


Figure 3-4.1

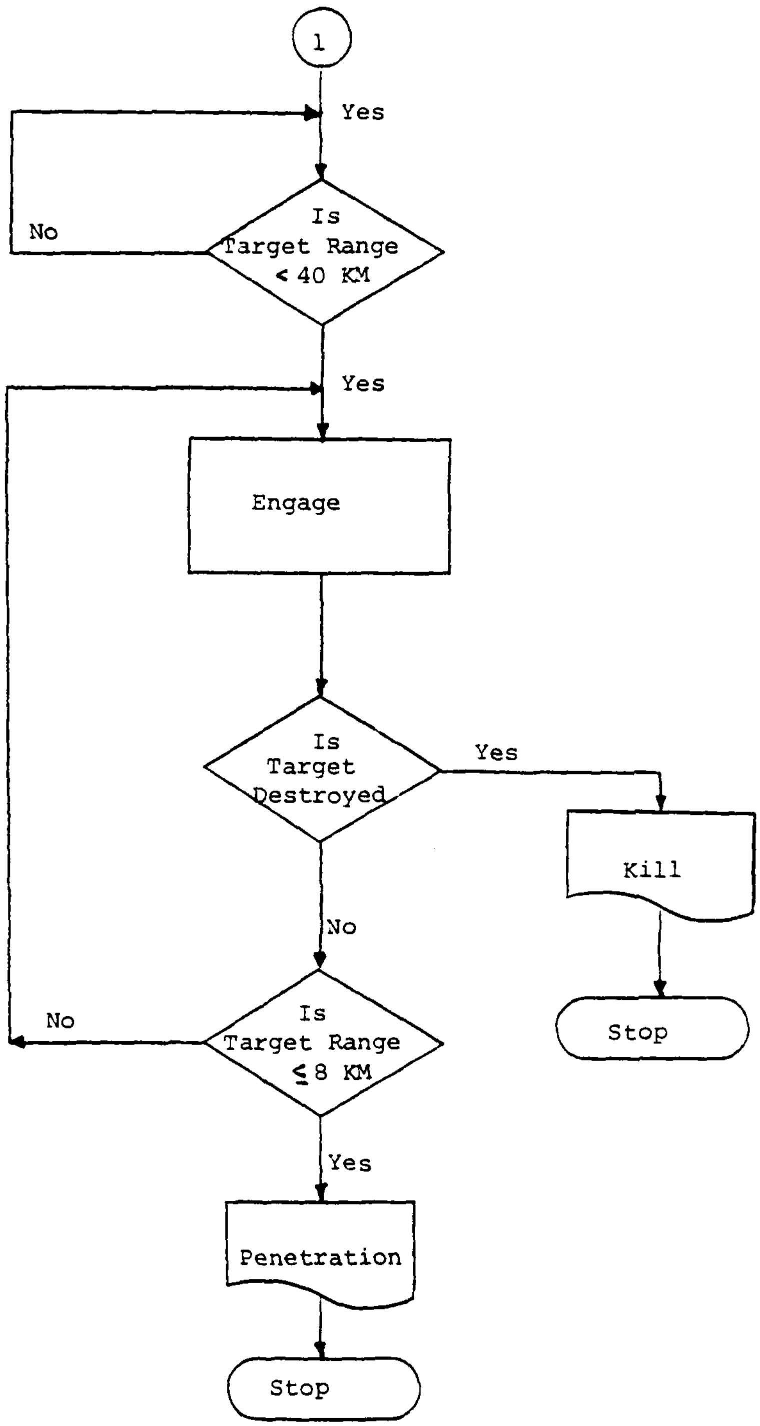

1
Yes
No
Is
Target Range
< 40 KM
Yes
Engage
Is
Target
Destroyed
Yes
Kill
Stop
No
No
Is
Target Range
≤ 8 KM
Yes
Penetration
Stop

Figure 3-4.2

the target is detected; otherwise, it is not. As the target moves closer to the unit, the probability of detection increases linearly. However, detection is not based on range alone. The target must be within the detection altitude capability of the operational system. For instance, if the battery's detection capability rests solely on the IPAR because of a nonoperational ICWAR and if the approaching target is at an altitude of less than 5000 feet, detection will never occur and a penetration will result.

Identification of the target is determined by either the IFF or a combination speed and altitude envelope if the IFF is nonoperational. Operational status of the IFF is determined by comparing, again, a generated random number from a 0-1 range uniform distribution against the operational ready rate of the IFF. If the random number is less than the ready rate, the IFF is operational; otherwise, it is non-operational. If the IFF is nonoperational and if the unit has a tracking capability, the target speed and altitude can be checked against an established hostile criteria. If the target is found to be below 5000 feet in elevation and above 550 KMPH in speed, it is designated a foe; otherwise, it is considered to not be a foe. Only targets positively identified as foes are engaged.

IFF positive identification of the hostile cruise missile as a foe is determined by comparing a random number generated from a 0-1 range uniform distribution against the IFF accuracy rate of 98 percent. If the random number is less than the accuracy rate, the cruise missile is correctly identified as a foe; otherwise, it is erroneously classified as a friend resulting in a penetration of the defended area.

The battery's engagement capability lies with its two firing sections, each tracking and firing on approaching hostile targets. Again, two random numbers drawn from the 0-1 uniform distribution are compared to the operational ready rates of the firing sections to determine the status as in the previous subsystems examples. If an engagement capability is determined to exist, the process continues on to direct missile firings at the target following target lock by the tracking radar(s). As mentioned earlier, this lock-on time is a function of operator training in the manual mode and is normally distributed. For highly trained operators the mean is assumed to be ten seconds with a standard deviation of five seconds. The lock-on time for each section is determined by two random numbers generated by the TI 59 random number generator from a normal distribution with mean and standard deviation determined by the user during program initialization. (Any random number less than zero is discarded and another generated to avoid negative times.) The length of the lock-on period directly affects the resultant target intercept range. If the lock-on time is sufficiently long the missile firing is delayed and the probability of a penetration is likely. (The determination of air battle results to varying lock-on times provided the basis for the development of this simulation, though other variables of the model can easily be tested for outcome sensitivity.) Again, targets are not engaged until less than 40 KM from the battery and no missiles are fired after the target is 8 KM or less from the battery.

Missile effectiveness after firing is determined when the IHAWK missile range equals or exceeds the cruise missile range from the battery. A random number from a 0-1 range uniform distribution is generated for each missile fired and checked against the P_{ssk}. Random numbers less than the P_{ssk} result in kills while all others result in no kills. Engagement of the target continues until a kill or penetration is registered.

C. MICRO FLOWCHART

The micro flowchart in appendix A depicts the detailed flow of processing throughout the simulation from start to kill or penetration.

D. SUBROUTINES, LABELS, FLAGS, DATA REGISTERS AND PROGRAM MEMORY STEPS

1. Subroutines and Labels

This simulation uses 49 of the 72 labels available for programming on the TI 59. Of these 49, 14 are subroutines. The remaining labels are used to identify sections of the program and to direct action to these sections during simulation runs. A complete listing of all labels is displayed in table 3-1 with the subroutines marked by an asterisk. Comments on selected labels and a printout of the entire program is enclosed in appendix A.

2. Flags

Nine of ten available flags are used. As the IHAWK equipment and target friend/foe status is determined, this model uses TI 59 flags to maintain a record of the system and target status. These flags subsequently direct the flow of processing and determine actions to be taken within the simulation engagement.

Flag 1 set means the target has been detected. Flag 2 set means the target is a friend. Flag 3 set means the ICWAR and the IPAR are operational. Flag 4 set means only the ICWAR is operational. Flag 5 set means only the IPAR is operational. Flag 6 set means the IFF is operational. Flag 7 set means that alfa firing section is operational and bravo firing section is nonoperational. Flag 8 set means that bravo firing section is operational and alfa firing section is nonoperational. Flag 0 set means that both firing sections are operational.

3. Data Registers

The TI 59 memory storage area is initially partitioned to provide 60 data storage registers and 480 program storage locations. However, the user can repartition the memory storage area to suit his particular programming needs. The IHAWK simulation requires exactly 800 program memory locations and 20 data storage registers. Within the TI 59 there are a total of 120 registers to be used for data storage and program locations. While each register can store only one datum point, each can store eight program instructions or steps. Thus 8 * 60 = 480 program locations which are initially available as mentioned above. Repartitioning the core 120 registers is done in increments of ten. Hence, to get the 800 program steps for the IHAWK simulation 100 core registers are needed. This leaves exactly the 20 needed for data storage.

To partition the storage area, the number of sets of 10 data registers needed is entered and 2nd OP 17 pressed. Thus for the IHAWK simulation, twenty data registers are available after the initial repartitioning by pressing 2 2nd OP 17. The registers and their contents are listed on the following page.

R_{00} Target range. Entered by user.

R_{01} R_{01} through R_{08} are used by the TI 59 random number generator program.

R_{02}

R_{03}

R_{04}

R_{05}

R_{06}

R_{07}

R_{08}

R_{09} SEED for random number generator. Entered by user.

R_{10} Mean lock-on-to-target time. Entered by user.

R_{11} Standard deviation of lock-on-to-target time. Entered by user.

R_{12} IHAWK missile range from battery. Initially zero.

R_{13} IHAWK missile range from battery. Initially zero.

R_{14} Probability of detection work register.

R_{15} Target speed. Entered by User.

R_{16} Target altitude. Entered by User.

R_{17} Target range work register. Not entered by user.

R_{18} Simulation trials or runs to be completed. Entered by user.

R_{19} Simulated time in seconds for each trial. Initially zero for each trial.

4. Program Memory Steps

There are 800 program steps available. All 800 program memory steps are used in this program.

E. USER INSTRUCTIONS

The enclosed user instructions, table 3-2, provide the necessary steps to initiate a sequence of simulation runs. The enclosed printout results, table 3-3, indicate the 22 possible print statements that may occur during the simulation. A sample of data input and simulation run results are displayed in tables 3-4 and 3-5.

Two steps of the user instructions warrant further comment.

1. Step 2 Clear Data Registers.

Instead of clearing all data registers the user may wish to clear selected registers when repeating simulation runs as in the case of sensitivity analysis work. In this instance the user may just clear registers R_{01}, R_{12}, R_{13}, R_{17}, R_{18}, R_{19} and enter the desired values. R_{09} need not be reentered as the program automatically changes the seed after each random number is generated. If the user does clear all data registers with 2d CMs the user must then enter an entirely different seed in R_{09} within the bounds noted.

2. Step 9 Check Data Register Content

This step is a quick safeguard for the user to ensure that the simulation run is based on the correct parameter values. This step provides a complete listing of the 20 data registers with contents for review prior to the final user step.

F. SENSITIVITY ANALYSIS RESULTS FOR LOCK-ON TIMES

Four hundred simulation runs were made with four lock-on mean values: 10, 20, 30 and 40 seconds. In each case the lock-on time standard deviation was five seconds. For each simulation run the target was initially set at a range of 30 KM in R_{30}, target speed was 1500 KMPH and target altitude was 7000 feet. An initial random number seed was entered for run number one but no further user seeds were provided, thus leaving seed manipulation to the program.

The results listed below indicate that air battle results are indeed sensitive to target lock-on times.

LOCK-ON TIME		PENETRATION	KILL
mu	sigma		
10	5	11%	89%
20	5	14%	86%
30	5	26%	74%
40	5	44%	56%

The results indicate a significant increase (12 percent) in defended area penetrations for a mu of 30 under the present scenario. This trend continues at an apparent exponential rate. With a mu of 40 seconds, defended area penetrations increase another 18 percent. Based on these results it appears advisable to maintain such a state of operator training that the mean target lock-on times be twenty seconds or less with as little deviation among the operators as possible. Furthermore, it seems that for the extra training assumed to be required to reduce mean lock-on times from 20 to 10 seconds there appears to be only a small marginal reward in the reduction of defended area penetrations (3 percent).

G. RECOMMENDATIONS

While the intent throughout the thesis is to exemplify the capabilities of the TI 59 as a viable, real world analytical tool, the results of the TI 59 simulation lend insight into an area that requires further investigation, that being IHAWK target lock-on times. While only the lock-on times themselves were varied for this simulation, other important scenario parameters should be varied to acquire an improved understanding of how air battle results can be affected by lock-on times.

Future enhancements of these results would include a significant increase in simulation runs for a wide variety of scenario parameter settings. While this TI 59 model allows certain parameter variations during program initialization, other parameters such as acquisition radar altitude detection capabilities can be varied with only minor adjustments to the program.

Regardless of whether future simulation studies are conducted using this TI 59 model or a facsimile on another computer, the results above warrant further research in this area.

030	39	COS
045	30	TAN
060	60	DEG
067	69	OP
099	17	B'
135	98	ADV
158	90	LST
170	42	STO
180	18	C'
203	14	D
208	16	A'
222	43	RCL
231	33	X²
235	15	E
251	52	EE
259	10	E'
278	19	D'
297	67	EQ
318	88	DMS
334	34	√X
338	23	LNX
354	24	CE
359	22	INV
378	32	X⇌T
393	25	CLR
411	28	LOG
455	38	SIN
*491	37	P/R
502	49	PRD
510	11	A
535	12	B
560	13	C
*585	50	I×I
*601	89	π
*610	79	x̄
*627	59	INT
*633	48	EXC
*639	80	GRD
*654	70	RAD
660	68	NOP
667	97	DSZ
677	58	FIX
*685	57	ENG
*708	29	CP
*722	96	WRT
*731	78	Σ+
*745	35	1/X
*760	45	YX
766	44	SUM

Table 3-1

USER INSTRUCTIONS				
STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	REPARTITION 800 PROGRAM MEMORY LOCATIONS 20 DATA MEMORY REGISTERS	2	2d OP 17	799.19
2	Enter magnetic program cards, sides 1 through 4			
3	CLEAR DATA REGISTERS		2nd CMs	(NO CHANGE)
4	RESET ALL FLAGS AND CLEAR ALL SUBROUTINE RETURN REGISTERS		RST	(NO CHANGE)
5	ENTER IHAWK SYSTEM DATA TRACKING RADAR "LOCK-ON" TIME	μ σ	STO 10 STO 11	μ σ
6	ENTER CRUISE MISSILE DATA	RANGE (KM) $10 < KM < 100$	GTO 777 LRN LRN	
		RANGE (KM) $10 < KM < 100$	STO 00	RANGE
		SPEED	STO 15	SPEED
		ALTITUDE (FT)	STO 16	ALTITUDE
7	ENTER SEED FOR RANDOM NUMBER GENERATOR ($0 \le S \le 199017$)	SEED	STO 09	SEED
8	ENTER DESIRED NUMBER OF SIMULATION RUNS	#	STO 18	#

Table 3-2.1

USER INSTRUCTIONS				
STEP	PROCEDURE	ENTER	PRESS	DISPLAY
9	CHECK DATA REGISTER CONTENT	0	RST INV 2d LIST	0
10	START SIMULATION RUN		R/S	(SEE RESULTS POSSIBLE)*

* PC-100 C PRINTER REQUIRED

Table 3-2.2

RESULT PRINTOUTS

NUMBER PRINTED	MEANING
1	CRUISE MISSILE HAS BEEN DETECTED AT (RANGE GIVEN IN KMs FROM UNIT)
3	LOW ALTITUDE DETECTION RADAR (ICWAR) AND MEDIUM ALTITUDE DETECTION RADAR (IPAR) ARE BOTH OPERATIONAL
4	ONLY ICWAR IS OPERATIONAL
5	ONLY IPAR IS OPERATIONAL
6	IDENTIFICATION FRIEND-OR-FOE (IFF) IS OPERATIONAL
7	ALFA FIRING SECTION IS OPERATIONAL, BRAVO FIRING SECTION IS NONOPERATIONAL
8	BRAVO FIRING SECTION IS OPERATIONAL, ALFA FIRING SECTION IS NONOPERATIONAL
9	BOTH FIRING SECTIONS ARE OPERATIONAL
10	CRUISE MISSILE IS IDENTIFIED AS A FOE
11	BRAVO FIRING SECTION IS FIRING ONE MISSILE AT A TARGET <40 KM FROM THE BATTERY, BUT GREATER THAN 8 KM
12	ALFA FIRING SECTION IS FIRING ONE MISSILE AT A TARGET <40 KM FROM THE BATTERY, BUT GREATER THAN 8 KM
14	CRUISE MISSILE IS ERRONEOUSLY IDENTIFIED AS A FRIEND BY IFF
15	CRUISE MISSILE IDENTIFIED AS NOT FOE BY SPEED AND ALTITUDE CRITERIA, IFF IS NONOPERATION
17	ALFA FIRING SECTION IS OPERATIONAL
18	ALFA FIRING SECTION IS NONOPERATIONAL
23	BATTERY IS NONOPERATIONAL, NO DETECTION CAPABILITY
24	BATTERY IS NONOPERATIONAL, NO FIRING CAPABILITY
25	ALFA SECTION MISSILE "NO KILL" FOLLOWED BY RANGE (KM) OF APPROACHING TARGET

Table 3-3.1

RESULT PRINTOUTS

NUMBER PRINTED	MEANING
26	BRAVO SECTION MISSILE "NO KILL" FOLLOWED BY RANGE (KM) OF APPROACHING TARGET
66	IFF IS NONOPERATIONAL
	TARGET "KILLS" ARE SPELLED OUT, I.E. "KILL", FOLLOWED BY THE RANGE FROM THE UNIT AT WHICH THE TARGET WAS DESTROYED
	"PENETRATION" IS PRINTED WHEN A CRUISE MISSILE APPROACHED WITHIN 8 KMs OF THE BATTERY. IN THIS INSTANCE THE UNIT IS CONSIDERED PENETRATED AND DESTROYED

Table 3-3.2

50.	00	Initial Target Range
0.	01	
0.	02	
0.	03	
0.	04	
0.	05	
0.	06	
0.	07	
0.	08	
111111.1111	09	Random number seed
30.	10	Mean lock-on time
5.	11	Standard deviation time
0.	12	
0.	13	
0.	14	
2500.	15	Target Speed (K.P.H)
7000.	16	Target altitude (feet)
0.	17	
100.	18	Simulation run #
0.	19	

Parameter Value Inputs To Selected Data Registers

Table 3-4

		Range of target kill (KM)
		B section missile fired
3.		Both Detection Radars Op
1.		Target detected
47.91666667		Target range at detection
6.		IFF is Op
10.		Target is a foe
18.		A Firing section is nonoperational
8.		B Firing Section is operational
11.		
KILL		
18.75		
18.75	00	
0.	01	
0.	02	
0.	03	
0.	04	
0.	05	
0.	06	
199017.	07	
5.16901038	08	
138731.7939	09	Next seed
10.	10	
5.	11	
20.	12	Range of IHAWK missile
0.	13	
.6314102564	14	
2500.	15	
7000.	16	
18.75	17	
95.	18	
45.	19	Elapsed simulation air battle time

Printout During Simulation and Data Register Contents

Table 3-5

IV. DATA ANALYSIS

A. PURPOSE

The purpose of this chapter is to demonstrate how the TI 59 may be used to analyze data. Rather than use assumed or contrived data, an actual experiment was conducted by the authors for illustrative purposes. Strict requirements for random sampling were not met in conducting the experiment but, again, the purpose of this thesis is to demonstrate the capabilities of the TI 59 rather than to make inferences or draw broad conclusions from the experimental data.

Before discussing methods for data analysis, the scope, design, and methodology of the experiment will be presented in sufficient detail to make the data analysis meaningful. Presentation of the experiment will be followed by a detailed discussion of a TI 59 program designed to compute measures of central tendency and spread for sample data. Chapter V discusses a TI 59 program which may be used to make statistical inferences using the same experimental data.

B. FITNESS EXPERIMENT

1. Scope of the Experiment

The experiment was conducted to test the hypothesis that different physical conditioning programs result in different levels of physical fitness. Six different conditioning programs were evaluated using five tests. The scope of the experiment was limited to testing the strength and endurance of selected upper body muscles, together with overall cardiovascular fitness. A completely comprehensive fitness evaluation would also include lower body strength and endurance as well as muscular flexibility and agility. Other factors such as diet, use of alcohol, tobacco and other drugs would also be requisite. This experiment was limited to the examination of thirty-six male subjects by the two authors to determine cardiovascular efficiency, bicep strength, bicep endurance, pectoral strength and pectoral endurance. Thirty of the subjects were military officers attending the Naval Postgraduate School. The other six subjects were weightlifters who trained at Bailey's Gym in Seaside, California. The subjects varied in age from nineteen to thirty-seven but were predominantly in their early thirties. While it is recognized that strict requirements for random sampling requisite for statistical analysis were not met in conducting the experiment, it should be pointed out that there is every reason to believe that the subjects examined were representative of the population from which students are continually drawn for the institution. Strict inference to any specified population will not be made, but as mentioned earlier the purpose of this discussion is to illustrate the use of programs developed for the TI 59, not to make inferences from the data gathered in this particular experiment.

Since the terms, strength, endurance, and cardiovascular efficiency are subject to a myriad of interpretations, the definitions used for this analysis are presented before proceeding to discuss the test methodology. Muscular strength is defined as the ability to exert maximum force against an object, while muscular endurance relates to the ability to exert force which is not necessarily maximal over an extended period of time. Cardiovascular efficiency relates to how well the heart, lungs and blood vessels work together without strain [Ref. 9] .

Before analyzing the results a thorough explanation of the experimental design and methodology is provided.

2. Experimental Design

The subjects were divided into six categories (each consisting of six individuals) based on their exercise programs. The following six categories were used: Category I - Individuals who had participated in no exercise over the last six months; Category II - Individuals who ran more than thirty miles per week and who did so for at least the last six months; Category III - Individuals whose exercise consisted solely of lifting weights, whether for power or building physique, and who lifted at least twice a week; Category IV - Individuals who lifted weights at least twice a week, who ran twenty or more miles per week and who did both the lifting and running for at least the last six months; Category V - Individuals who lifted weights at least twice a week, who ran between ten and nineteen miles per week, and who did the lifting and the running for at least the last six months; and Category VI - Individuals who did not run or lift weights but who participated in basketball, racquetball, bicycling, or judo on a regular basis.

Five tests were administered to each subject in each category. Cardiovascular efficiency was measured using the Pipes Test for Cardiovascular Health, which consists of the following seven steps:

1. Have the subject lie quietly on a pad for ten minutes.
2. Take a pulse reading for the resting heart rate.

3. Have the subject sit on a chair with his arms folded across his chest.

4. With his arms folded, have the subject stand up and sit down twice every five seconds for three minutes.

5. Take a reading for the heart rate immediately after sitting down at the conclusion of the three minute exercise.

6. Take readings at 30-second, 60-second, and 120-second intervals after the exercise to measure recovery heart rate.

7. Using a table developed by Pipes and the five heart rate readings determine the cardiovascular health score.

This test, developed by an exercise physiologist, [Ref. 9] is based on the premise that the heart rate describes an individual's fitness in three areas: how much oxygen he needs, how much blood his heart has to pump to meet the oxygen need, and how hard the heart works. Individuals with a low level of fitness do not extract oxygen efficiently from the blood so must pump more blood, resulting in a higher heart rate. In conducting the test, the same examiner took the pulse readings at the different intervals using the radial artery in the subject's wrist. The heart rate was monitored for ten seconds then multiplied by six to obtain the number of heart beats per minute.

The muscular strength test used for biceps was the maximum standing curl the individual could accomplish using a barbell. The proper technique was demonstrated to each subject by the examiner and lifts where the individual "cheated" by swinging the weight or arching his back were not counted. Bicep endurance was measured by the number of curl repetitions the subject performed with a 55 pound weight. These two tests were predicated on the generally accepted basis that curling is the primary bicep exercise and that low repetition, high resistance exercises are best for developing endurance [Ref. 3]. Fifty-five pounds of weight were selected prior to the experiment as a low resistance weight well below each subject's strength capability and therefore in compliance with expert opinion that the force used for endurance testing should be considerably below the individual's static force capability [Ref. 7].

In a similar fashion, the bench press was used to test pectoral strength and endurance. Pectoral strength was measured by the maximum weight that the individual could bench press, while pectoral endurance was measured by the number of bench press repetitions he could perform.

Each subject was tested using an identical sequence of events. Initially each person was given an instruction sheet (table B-1 in Appendix B) which explained the purpose of the experiment and defined those attributes to be measured, i.e. muscular endurance, muscular strength, and cardiovascular health. The subject was then asked to complete a questionnaire (table B-2, Appendix B) concerning certain aspects of his medical history. Each man was instructed to stop the testing if he felt any significant level of pain. He was then asked to complete a form disclosing his name, age, weight, and height (table B-3, Appendix B). Next, one of the examiners questioned the subject concerning his exercise program over the last six months and made a subjective judgement as to which of the six categories he belonged in.

After this administrative procedure was completed, the actual testing was begun with the bench press test described above. (The same examiner tested each of the thirty-six subjects in both the strength and endurance exercises in order to minimize any variance due to test administration.) The subject was shown how to do the bench press, allowed to practice once if desired, and then tested for the maximum number of repetitions he could perform with 100 pounds. The number of repetitions was recorded and the subject was allowed a three minute rest before being tested for his maximum bench press. The examiner estimated the amount that each subject could bench press and set up the weights accordingly. All adjusting of weight was done by the examiner so that the subject's lift capability was not degraded. The man was then asked to bench press the weight set up for him. If he was able to make the lift ten pounds were added and he was asked to try again. If he failed the second attempt he was given credit for five pounds less than he attempted. For example, if an initial attempt of 165 pounds was successful and a subsequent attempt of 175 pounds was missed, then the score was recorded as 170 pounds.

After another three minute rest the subject was tested on the number of times he could curl 55 pounds. This was followed by another three minute rest before testing for his maximum curl capability. Once again, the man's maximum lift was estimated by the examiner and all adjusting of the weight was done by the examiner.

Following the four lift tests, the Pipes Cardiovascular Health Test [Ref. 9] was administered by the second examiner and the subject's testing was completed. Before examining the test results, a procedure for scoring the tests was requisite. Accordingly, the scoring procedure explained in the following discussion was decided upon.

3. Scoring Methodology

The heart rates recorded during the Pipes Cardiovascular Test were scored using table B-4 in Appendix B. Each subject's score for resting heart rate, heart rate immediately after the exercise and heart rate at the 30-second, 60-second, and 120-second intervals was aggregated to a total score ranging from zero to one hundred. This score was then used as the measure of cardiovascular fitness for comparative analysis.

In order to compare muscle strength among the subjects and among the categories, it was necessary to adjust each subject's lift for varying sizes and body structures. Accordingly, each man's maximum curl and maximum bench press were divided by his body weight, resulting in an adjusted score for each lift. These two adjusted scores were then added together to yield an upper body strength measure. For example, let S_{13} be the strength measure for the third subject in Category I (where the first subscript indicates the category and the second indicates the subject within the category). The following formula may then be used to obtain the strength score for the third subject tested in Category I:

$$S_{13} = \frac{\text{maximum bench + maximum curl}}{\text{body weight}}$$

As discussed earlier, muscle endurance was measured for the same two areas tested for strength - the biceps and the pectorals. The bicep endurance was measured by the maximum number of curl repetitions performed with 55 pounds, while the pectoral endurance was measured by the maximum number of bench presses accomplished with 100 pounds. As in the case of strength, an adjustment was made for the subject's body weight. In the case of endurance, however, the amount of weight lifted (which was 55 pounds for the curl and 100 pounds for the bench press) was divided by the subject's body weight and then multiplied by the corresponding number of repetitions lifted. These two scores were then summed as the endurance index. For example, let E_{13} be the endurance score for the third subject tested in Category I. The following formula then obtains:

$$E_{13} = \frac{100 \text{ lbs}}{\text{body weight of subject}} * (\text{number of bench press repetitions})$$

$$+ \frac{55 \text{ lbs}}{\text{body weight of subject}} * (\text{number of curl repetitions})$$

4. Test Results

Tables B-5 through B-10 in Appendix B reflect the results of the experiment for each of the six categories tested. For example, table B-5 depicts the age, weight, cardiovascular score, adjusted strength score and adjusted endurance score for each of the six subjects tested in Category I. Appropriate references are made at table B-5 for the development of the final cardiovascular, strength and endurance scores. The scoring methodology section of the chapter provides a detailed explanation of the rationale and methodology for deriving these scores.

C. TI 59 PROGRAM FOR DATA ANALYSIS

Having developed the experimental design, the scoring methodology, and the test results it is now possible to analyze the data. Measures of central tendency and spread will be used to illustrate an application of the TI 59 in analyzing sample data. The measures of central tendency used for this illustration are the mean, $\overline{x}$, and the median. The measures of spread used are: the sample variance, s^2; the standard deviation, s ; the mean absolute deviation, MAD; the mean squared deviation, MSD; the root mean squared deviation, RMSD; and the range. A TI 59 program will now be described in detail which computes these measures followed by an example applying the program to the results of the fitness experiment.

1. <u>TI 59 Capabilities</u>

The TI 59 has been hard-wired to calculate the sample mean and variance as well as MSD. As described in the TI 59 Personal Programming Manual [Ref. 12] if each datum is entered into the calculator followed by pressing the $\Sigma+$ key, the calculator will sum each data entry, x_i, into register one, sum the squares of x_i into register two, store the number of data entries in register three, and calculate $\overline{x}$, s^2, and MSD. (By definition, $s^2 = 1/n-1 \sum(x_i - x)^2$ is the unbiased estimator for σ^2 while MSD = $(n-1)s^2/n$ is the maximum likelihood estimator.) Pressing the $\overline{x}$ key will yield the mean, INV $\overline{x}$ will display s^2 and 2nd Op 11 will display MSD. If these are the only measures desired then utilization of the $\Sigma+$ key is the most expedient method of obtaining them. The TI 59 statistics module has a program (Program 03) which computes these same measures as well as the middle value (MIDVAL). Additionally, Program 03 stores each data entry beginning with register 31. Program 03 also computes a number of other quantities not germane to an analysis of the data gathered in the experiment discussed previously in this chapter. Since this results in a slightly longer run time for each computation, a program has been written by the authors which exploits the hard-wire capabilities of the $\sum+$ key, computes MAD and range in addition to the other measures discussed, and stores the data for recall or transformation if desired. In addition, this program may be used with the TI 59 Master Module if the Statistics Module is not available. The following section describes the program in detail.

2. Univariate Data Program

In order to facilitate the description of this program a flowchart (figure 4-1), has been included at the end of the chapter. Comments in the paper are keyed to figure 4-1 by numbered circles for easy reference.

The program is initialized by pressing E' (figure 4-1, 1). Initialization entails clearing all of the data registers, lowering flag 0 the purpose of which will be addressed later, and storing 31 in register 30. Register 30 is used as a post office for indirect addressing. In this particular program this means that data are stored in the register indicated by register 30. For example, after initialization, register 30 contains 31. The sequence x_1, STO 2nd IND 30 will result in x_1 being stored in register 31. When the initialization routine, 2nd E', is complete the display will contain the value 31. Each datum may now be entered successively followed by pressing A. The routine at Label A begins by storing x_i in a working, register 18 (figure 4-1, 2). x_i is then stored permanently beginning in register 31. x_1 is stored in register 31, then register 30 the indirect storage address is incremented by 1 so that x_2 will be stored in register 32, x_3 in register 33 and x_n in register 31 + n - 1. A total of sixty-nine entries may be made using registers 31 through 99 for data storage. Registers 0 through 29 are used to make the requisite computations of central tendency and spread. After each datum, x_i, has been stored, the program checks to see if flag 0 is raised (figure 4-1, 3). If flag 0 is raised this indicates that a data entry has been made previously, ie., the current x_i is not x_1. In this event the program skips to Label x. If flag 0 is not raised, ie., the current x_i is x_1, then x_1 is recalled from the working register, register 18, and stored in register 12 as the minimum x_i and register 13 as the maximum x_i. Future entries may then be checked against register 12 to determine which value is lower. If a current x_i is lower than the value in register 12 then it will replace it as x_{min}. Similarly, subsequent entries may be checked against register 13 in order to retain x_{max}. After storing x_1 in register 12 and in register 13 the program internally calls the key which, as disscussed previously, will sum x_i into register 01, sum x_i^2 into register 02, sum the number of entries into register 03 and compute $\overline{x}$, s^2, and MSD. Flag 0 is then raised so that subsequent entries will skip to Label x and replace x_{min} or x_{max} as appropriate. The program then recalls the number of entries, n, into the display and stops awaiting the next entry (figure 4-1, 4). The second entry x_2 will now be stored temporarily in the working register, register 18, and permanently in register 32. The indirect addressing register, register 30, is incremented by 1 for the next entry and the program then checks to see if flag 0 is raised. Since this is not the first entry, the flag will be raised causing the program to skip to Label x (figure 4-1, 5). The first step under Label x is to recall x_{min} from register 12 and store it in the test register R_T. For this particular iteration, x_1 will be in register 12 since the first entry was both the maximum and the minimum value processed as described earlier. The program then recalls the current x_i (x_2 in this instance) from the working register, register 18. The display value, x_2, is checked against the R_T value, x_1, to see if the display value is less than the R_T value. If so the program skips to step 57 where x_2 is stored in register 12, replacing x_1 as the lowest data entry (figure 4-1, 6). If the display value is not less than the R_T value then the program recalls x_{max} from R_{13} and stores it in R_T. x_i is recalled from the working register, register 18, into the display. This time the program checks to see if the display value, x_i is greater than the R_T value, x_{max}. If so, the program skips to step 62 where x_i is stored in register 13 as the new x_{max} (fig. 4-1, 7). The program then computes the MIDVAL by recalling x_{min} from register 12 and x_{max} from register 13, summing them and dividing by 2, and storing in register 14. Next the range is computed by subtracting x_{min} from x_{max}. The range value is stored in register 15 (figure 4-1, 8). The program then loops back to the + key to compute the mean, variance and MSD, (figure 4-1, 9). The number of entries is recalled and displayed awaiting the next entry. This process is repeated until all of the data have been processed.

The outputs of the program may be recalled as shown in table 3-11 in Appendix B. The mean is displayed by pressing $\overline{x}$, the variance by pressing Inv $\overline{x}$, and MSD by pressing 2nd op 11. The lowest data point, x_{min}, may be discovered by recalling register 12 while the highest data entry, x_{max}, may be recalled from register 13. Recalling register 14 will display the MIDVAL and the range may be found by recalling register 15. Each of the original data entries may be recalled if desired beginning with x_1 in register 31. MAD is computed by pressing 2nd A' which calls a different subroutine. This subroutine recalls $\overline{x}$ which was computed under Label A and stores it in Register 16. The number of entries, n, is recalled from register 3 and stored in register 7 to be used as a decrement register. Register 20 contains 31 which is used to indirectly address the datum which have been stored beginning with register 31. The program recalls each x_i using register 20 and subtracts $\overline{x}$. The absolute value of the difference is summed into register 19. The program does this successively for each x_i until the decrement register, register 20, is equal to zero indicating that each x_i has been processed. The sum of the absolute values of the deviations from the mean is recalled from register 19 and divided by n which is recalled from register 3. This value, the mean absolute deviation is displayed completing the subroutine A' processing. All the values discussed earlier are still intact and may be recalled if needed. Table B-12, Appendix B, is a program listing for the univariate program.

D. APPLICATION OF THE TI 59 UNIVARIATE PROGRAM

The cardiovascular scores for Category I provide a ready example for the use of the univariate program to calculate measures of central tendency and spread. After the program card has been read in, the program is initialized by pressing 2nd E'. The cardiovascular scores for Category I (table B-5) are entered into the calculator as follows: 56.5, A; 58, A; 58, A; 44.5, A; 33.5, A; 40, A. The instructions contained in table B-11 may then be used to obtain the desired statistics. For this particular example: 2nd x yields the mean, 48.4; RCL 14 displays the MIDVAL, 45.75; RCL 15 displays the range, 24.5; 2nd A' yields the mean absolute deviation, 9; 2nd Op 11 displays the mean squared deviation, 92.9; 2nd Op 11, $\sqrt{x}$, calculates the root mean squared deviation, 9.6; INV 2nd $\overline{x}$ recalls the standard deviation, 10.56; INV 2nd $\overline{x}$, x^2 calculates the variance 111.5; RCL 12 displays the lowest data entry, 33.5 and RCL 13 displays the highest data entry, 58. To calculate the sample statistics for another category or for a different test the user need only push 2nd E' to re-initialize and then enter the relevant data. Statistics have been calculated for the age, weight, cardiovascular scores, endurance scores, and strength scores for each of the six categories. Tables 4-1 through 4-6 display these statistics. Rather than discuss each of these tables in depth, one example is provided relative to the interpretation of the sample statistics.

The cardiovascular mean for Category I, 48.4, indicates average cardiovascular fitness using the Pipe's test which is based on a scale from 0 to 100. Three measures of spread (standard deviation 10.56, root mean squared deviation, 9.6, and mean absolute deviation, 9) are approximately equal to ten, a rather high variability in this case. The range, 24.5, also indicates that the data are quite spread out.

x_{min} of 33.5 and x_{max} of 58, the bounds of the sample data indicate that the cardiovascular fitness of sedentary people varies from poor to average.

Inferences, subject to the sampling limitations already discussed, may also be made about the strength or endurance of sedentary people using the data from table B-5. Similarly, the statistics for the other categories may be used to make inferences about the strength, endurance, or cardiovascular fitness of those who run over thirty miles per week (Category II) or those who lift weights (Category III) or any of the other three categories. Programs have also been written for the TI 59 which allow a user to develop confidence intervals for these sample statistics [Ref. 14] .

The next chapter will discuss a program for one factor analysis of variance and then apply the program to the fitness data to illustrate statistical inference with the TI 59.

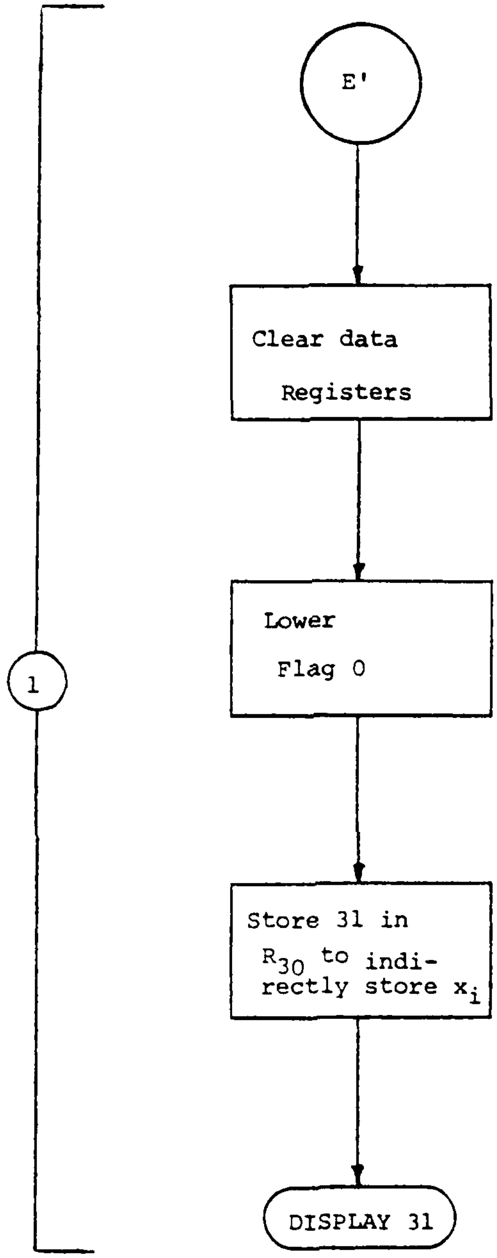

E'
Clear data
Registers
Lower
Flag 0
1
Store 31 in
R_{30} to indi-
rectly store x_i
DISPLAY 31

Figure 4-1.1

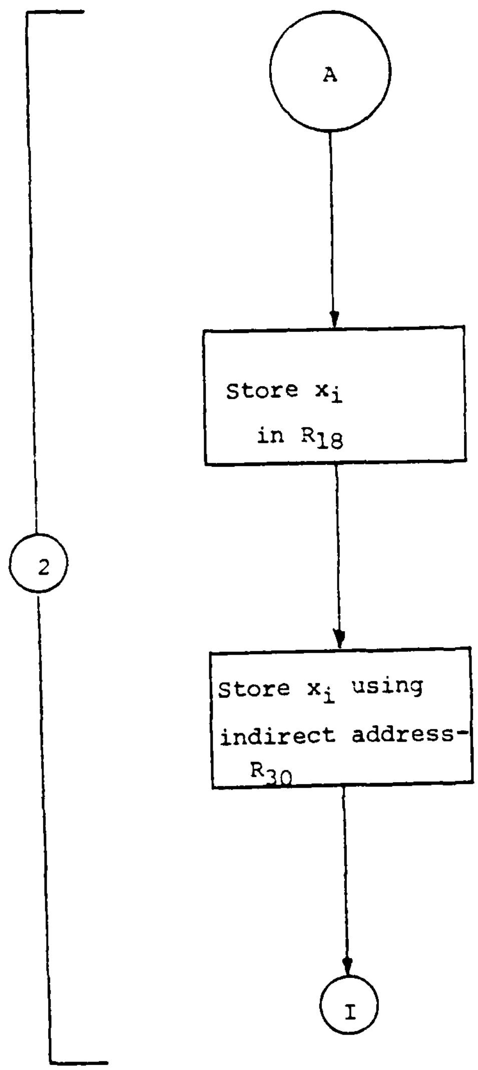


Figure 4-1.2

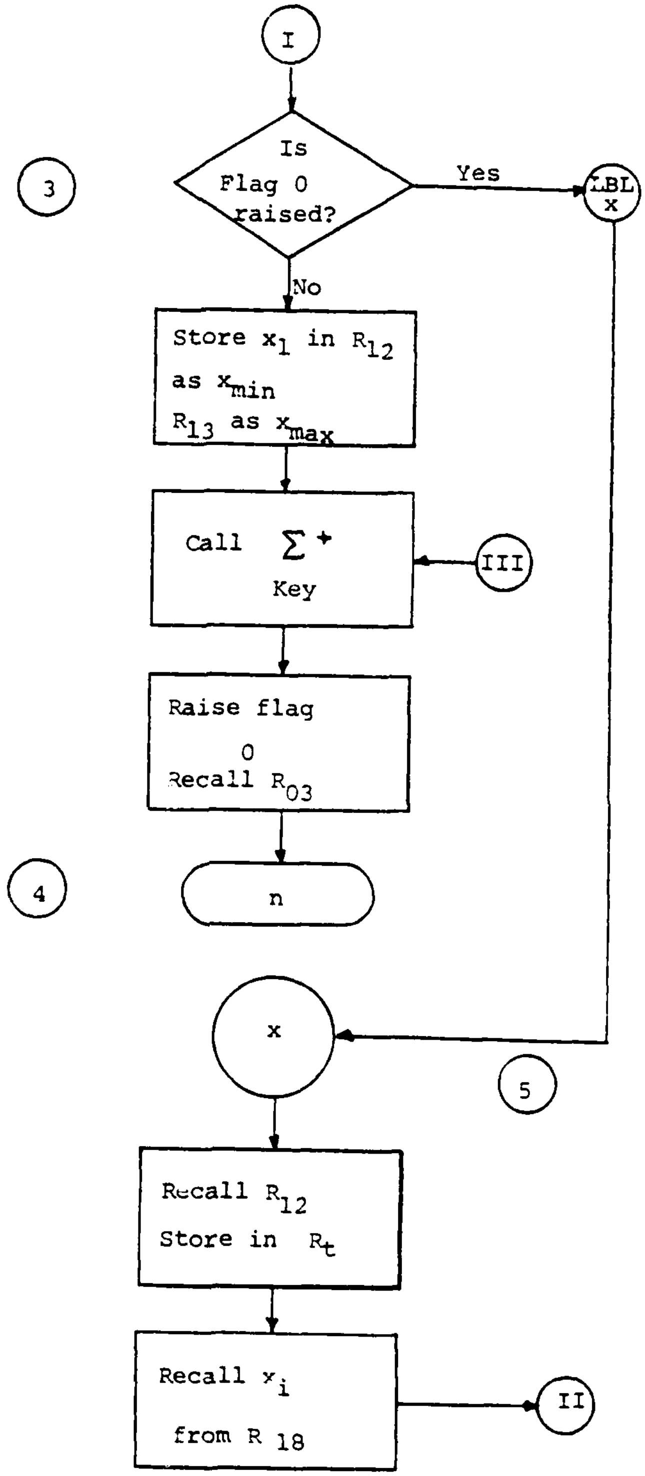

I
Is
Flag 0
raised?
Yes
LBL
x
3
No
Store x_1 in R_{12}
as x_{min}
R_{13} as x_{max}
Call Σ^+
Key
III
Raise flag
0
Recall R_{03}
4
n
x
5
Recall R_{12}
Store in R_t
Recall x_i
from R 18
II

Figure 4-1.3

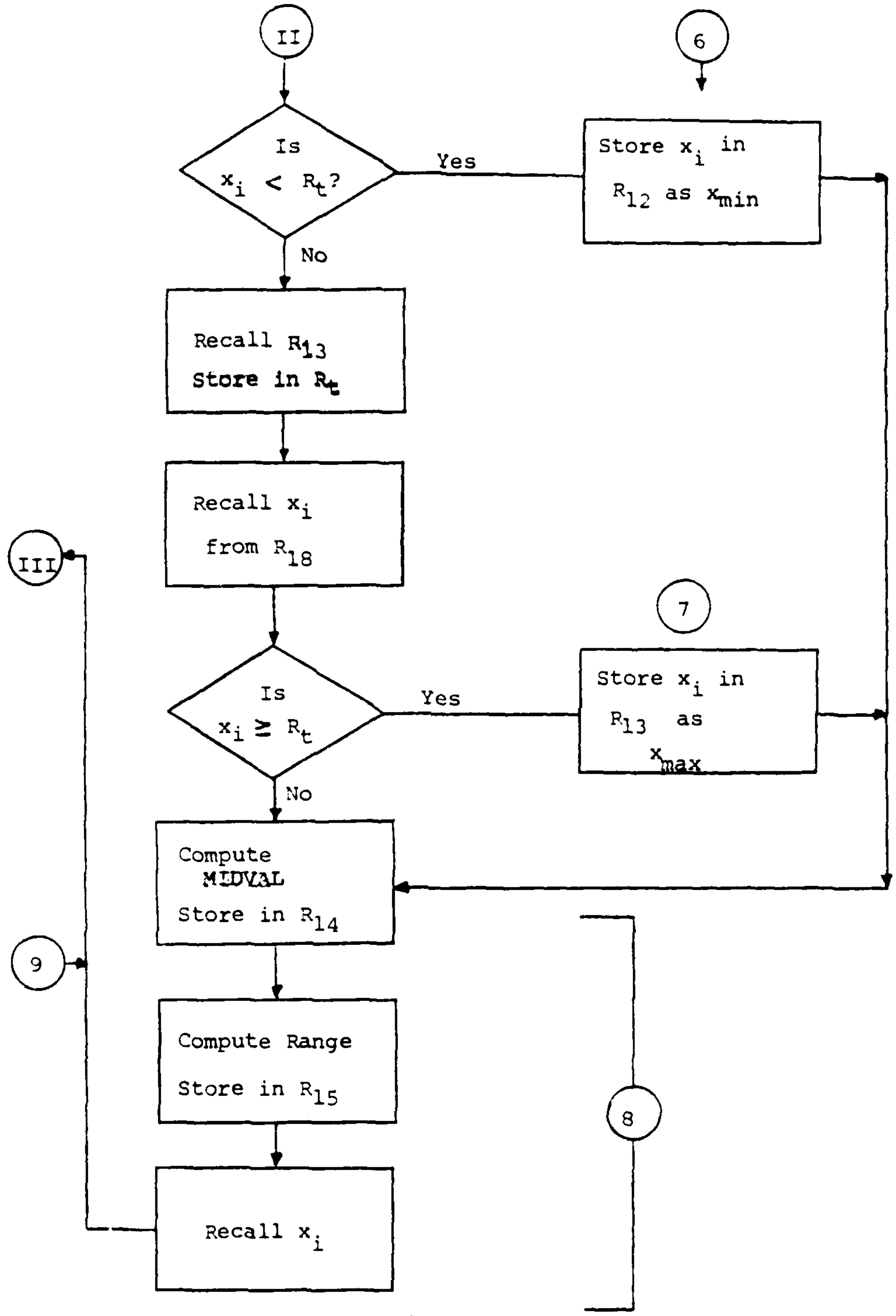
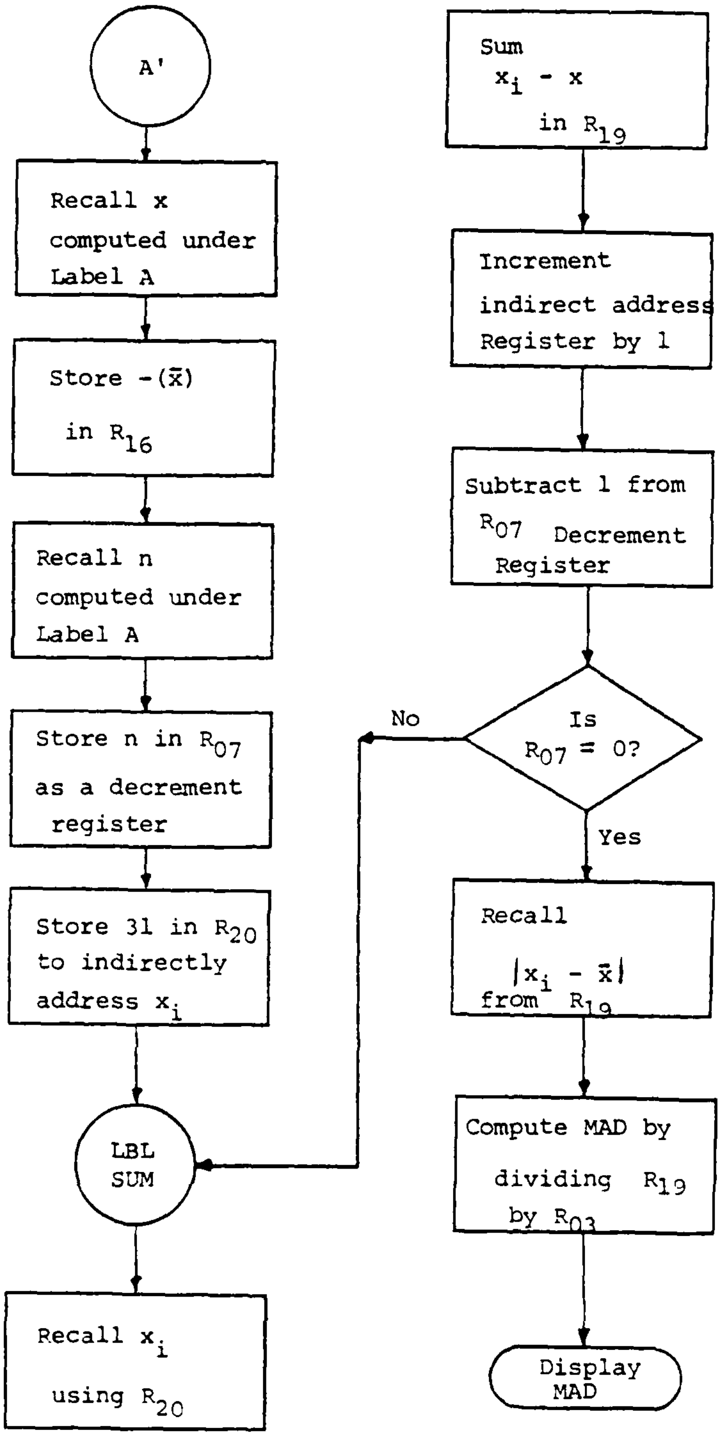

II
6
Is
x i < Rt?
Yes
Store x i in
R12 as xmin
No
Recall R13
Store in Rt
Recall xi
from R18
III
7
Is
xi ≥ Rt
Yes
Store xi in
R13 as
xmax
No
Compute
MIDVAL
Store in R14
9
Compute Range
Store in R15
8
Recall xi

Figure 4-1.4



A'
Recall x computed under Label A
Store -(x̄) in R_{16}
Recall n computed under Label A
Store n in R_{07} as a decrement register
Store 31 in R_{20} to indirectly address x_i
LBL SUM
Recall x_i using R_{20}
Sum x_i - x in R_{19}
Increment indirect address Register by 1
Subtract 1 from R_{07} Decrement Register
Is R_{07} = 0?
No
Yes
Recall $|x_i - \bar{x}|$ from R_{19}
Compute MAD by dividing R_{19} by R_{03}
Display MAD

Figure 4-1.5

CATEGORY I STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	33.3	33.00	8.00	2.30	9.0	3.00	7.5	2.74	37.0	29.0
WEIGHT	172.8	180.00	50.00	16.40	412.0	20.30	345.1	18.58	205.0	155.0
CARDIO SCORE	48.4	45.75	24.50	9.00	111.5	10.56	92.9	9.60	58.0	33.5
STRENGTH SCORE	1.17	1.15	.35	.085	.014	.12	.012	.11	1.32	.97
ENDURANCE SCORE	15.25	16.70	22.40	7.17	76.7	8.70	63.9	8.00	27.9	5.5

TABLE 4-1

CATEGORY II STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	32.2	31.5	7.0	2.11	6.96	2.6	5.8	2.41	35.0	28.0
WEIGHT	164.5	161.0	68.0	16.16	529.0	23.0	440.9	20.99	195.0	127.0
CARDIO SCORE	83.4	75.75	41.5	10.4	229.9	15.16	191.6	13.8	96.5	55.0
STRENGTH SCORE	1.31	1.29	.36	.13	.026	.16	.022	.15	1.47	1.11
ENDURANCE SCORE	14.96	17.7	22.4	6.99	78.96	8.89	65.8	8.11	28.9	6.5

TABLE 4-2

CATEGORY III STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	26.8	28.0	12.0	3.5	19.76	4.45	16.4	4.06	34.0	22.0
WEIGHT	205.3	202.5	45.0	11.4	256.6	16.0	213.9	14.6	225.0	180.0
CARDIO SCORE	52.25	55.5	62.0	17.6	506.4	22.5	422.0	20.5	86.5	24.5
STRENGTH SCORE	2.39	2.42	.83	.20	.078	.279	.065	.255	2.83	2.0
ENDURANCE SCORE	46.46	47.05	30.9	9.3	132.0	11.49	110.0	10.49	62.5	31.6

TABLE 4-3

CATEGORY IV STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	28.0	25.5	13.0	3.67	25.2	5.02	21.0	4.58	32.0	19.0
WEIGHT	187.5	200.0	80.0	21.67	857.5	29.3	714.6	26.7	240.0	160.0
CARDIO SCORE	83.4	84.0	25.0	6.9	78.3	8.85	65.3	8.1	96.5	71.5
STRENGTH SCORE	2.23	2.26	.82	.22	.084	.29	.07	.27	2.67	1.85
ENDURANCE SCORE	44.38	41.65	14.7	3.59	28.2	5.3	23.5	4.9	49.0	34.3

TABLE 4-4

CATEGORY V STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	28.7	27.0	16.0	4.7	37.5	6.1	31.2	5.6	35.0	19.0
WEIGHT	171.5	162.5	85.0	19.3	813.0	28.5	677.9	26.0	205.0	120.0
CARDIO SCORE	55.8	58.5	38.0	8.7	165.7	12.9	138.1	11.8	77.5	39.5
STRENGTH SCORE	1.83	1.79	1.28	.28	.176	.419	.146	.38	2.43	1.15
ENDURANCE SCORE	34.4	38.0	32.1	10.8	178.6	13.4	148.8	12.2	54.1	22.0

TABLE 4-5

CATEGORY VI STATISTICS

	MEAN	MIDVAL	RANGE	MAD	S^2	S	MSD	RMSD	X_{max}	X_{min}
AGE	30.7	30.0	6.0	1.44	4.26	2.06	3.56	1.89	33.0	27.0
WEIGHT	170.8	165.0	80.0	15.8	674.2	25.96	561.8	23.7	205.0	125.0
CARDIO SCORE	70.9	67.0	39.0	12.9	239.9	15.5	199.9	14.1	86.5	47.5
STRENGTH SCORE	1.36	1.36	.41	.11	.020	.14	.016	.13	1.56	1.15
ENDURANCE SCORE	16.6	17.25	11.7	2.83	15.38	3.9	12.8	3.58	23.1	11.4

TABLE 4-6

V. STATISTICAL INFERENCE

A. PURPOSE

The purpose of this chapter is to illustrate a method of statistical inference using the TI 59. As in chapter IV the intent is to demonstrate the capabilities of the TI 59 rather than to emphasize statistical principles. One-way analysis of variance (ANOVA) will be used to demonstrate statistical inference using the fitness data discussed in the preceeding chapter. The variations of the underlying populations represented by the six categories are assumed to be unknown but equal for this illustration.

B. TI 59 PROGRAM FOR ANALYSIS OF VARIANCE

In testing the hypothesis that the population means for each of the six test categories are equal, H_0 is typically rejected if the F ratio exceeds the critical F value in a standard table for the desired test level (typically 5%). Alternatively, using the TI 59 to its full advantage, prob-value may be used to test H_0. Prob-value is a method of testing whether or not the null hypothesis is supported by the data. In the case of the F ratio, prob-value is the probability that the F ratio would be as large or larger than the value actually observed if H_0 were true. This is the right hand tail area, Q (f), where

$$Q(f) = Pr\ (F > f)$$

Prob-value has the advantage that analysis is not restricted to arbitrarily established test levels such as 5% or 10% or to use of standard published tables. The TI 59 Statistics Module has an F distribution program (Program 22) which computes the tail area of an F curve where the curve is defined by the degrees of freedom in the numerator and the denominator. A series expansion is used to approximate the integral to determine Q(f) [Ref. 10] . If H_0 is true, indicating that all of the observations are from the same normal population, then the prob-value, Q(f), will be large. Conversely, if H_0 is false then the prob-value will be small. If the prob-value is sufficiently small (as determined by the decision-maker) then H_0 is rejected and the conclusion is formed that there must be a difference in the population means somewhere [Ref. 14] .

While a classical test or prob-value may facilitate rejection or acceptance of the null hypothesis, no insight is provided as to which means differ, given that H_0 is rejected. There is an efficient method developed by Sheffe [Ref. 13] for computing confidence intervals for the difference between means. If the physical fitness example discussed earlier is used, then Sheffe's development may be used to make the following statements with 95% confidence:

$$(\mu_1 - \mu_2) = (\bar{X}_1 - \bar{X}_2) \pm \sqrt{(r-1)F_{.05}}\, S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

$$(\mu_1 - \mu_3) = (\bar{X}_1 - \bar{X}_3) \pm \sqrt{(r-1)F_{.05}}\, S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_3}}$$

$$(\mu_2 - \mu_3) = (\bar{X}_2 - \bar{X}_3) \pm \sqrt{(r-1)F_{.05}}\, S_p \sqrt{\frac{1}{n_2} + \frac{1}{n_3}}$$

Where $F_{.05}$ is the critical value of F which leaves 5% in the upper tail, S_p is the square root of the pooled variance, r is the number of means compared, and n is the size of each of the samples. In the fitness example this equates to making confidence statements about the difference in fitness between the six categories where r is six and n is 6 for each of the samples. To facilitate multiple comparisons a contrast of means is used. This contrast may be written as:

$$\sum c_i \mu_i \quad \text{where} \quad \sum c_i = 0$$

It is then possible to develop the following formula which includes all possible contrasts with 95% confidence:

$$\sum c_i \mu_i = \sum c_i x_i \pm \sqrt{(r-1) F_{.05}}\; S_p \sqrt{\sum \left(\frac{c_i}{n_i}\right)^2}$$

If the value 0 is included in a confidence interval then there is no basis for believing that the population means differ while if 0 is not included then the conclusion is drawn that the means do in fact differ.

A program has been developed by Dr. P.W. Zehna [Ref. 14] for the TI 59 which computes the elements of an ANOVA table (table B-15)to include the F ratio and prob-value discussed above. Basically the program exploits the TI 59 F distribution program for determining prob-value (Program 22) after using Program 15 of the Statistics Module [Ref. 10] to calculate the F statistic. The program then uses Scheffe's multiple contrasts to determine which population means differ given that the null hypothesis is rejected.

A flowchart (figure 5-1), user instructions (table B-13), and a listing of the actual program steps (table B-14) are provided to facilitate description of the ANOVA program. The program takes data input by rows and outputs the elements of an ANOVA table (table B-15) sequentially as indicated by the number in each block of the table. A row of data constitutes a sample as in the example at table B-16.

The program begins by using Program 06 of the Statistics Module to enter the data. After initialization with 2nd E' each x_{ij} is entered followed by pressing Label A. When one complete row has been entered a press of 2nd B' causes the calculator to compute the row or sample x and a press of 2nd C' results in computation of the MSD. These two steps must be performed after each row has been input so that the calculator will know when a new row is being entered. When all of the data have been entered using this scheme (table B-13) the sequence RST, A begins the ANOVA Table calculations. The first step under Label A is to call Program 15 of the TI 59 Statistics module which computes the F ratio. In the process of computing the F ratio the other elements of the ANOVA table (table B-15) are computed and stored except for the prob-value. To fill in the values for the ANOVA table all that is required is successive pushes of R/S as indicated in table B-13. For example, the first R/S displays the degrees of freedom for the numerator while the fourth R/S displays the degrees of freedom for the denominator. The program essentially recalls and displays the calculations of Program 15 of the Statistics Module to build the ANOVA table. To compute prob-value the program internally calls Program 22 of the Statistics Module. The user need only press R/S as indicated in table B-13 which causes the calculator to recall the degrees of freedom for the numerator and the denominator used in Pgm 15 and transfer them to Program 22 to define the F Distribution. The F statistic calculated in Program 15 is then recalled and transfered to Program 22 resulting in $Q(f)$, the probability that $F > f$. This prob-value may then be used to accept or reject the null hypothesis. If the null hypothesis is accepted then the analysis is completed. However, if H_0 is rejected, the next step entails the use of Scheffe's contrasts to determine which means differ.

To use the ANOVA program (table B-14) for posterior contrasts with Scheffe's formulas the user initializes the routine by pressing 2nd E'. Then c_i, x_i and n_i are entered for each row as shown in table B-13. The c_i's are the coefficients used to determine which means are contrasted as discussed previously. To contrast u_1 and u_2, $c_1 = 1$, $c_2 = -1$ and all other $c_i = 0$. To contrast u_2 and u_3, $c_2 = 1$, $c_3 = -1$ and all other $c_i = 0$. As these data are input, the program uses a 'loop' to calculate $\sum\left(\frac{C_i^2}{n_i}\right)$ which is stored in register 03 and $\sum C_i X_i$ which is stored in register 06, (figure 5-1). Register 04 is used as a counter to display the number of row entries. After each c_i, x_i and n_i entry, register 04 is incremented by one. The program then transfers to Label x^2, displays the running count of row entries and stops pending the next entry. After every c_i, x_i and n_i have been processed, a critical value of F with degrees of freedom r-1 and n(r-1) is entered for the desired test level followed by 2nd A'. The program recalls the degrees of freedom for the numerator, r-1, from register 14 and the pooled variance S_p^2 from register 29. The product $(r-1)\ F_2)S_p^2$ is formed and multiplied by the contents of register 03 $\sum\left(\frac{C_i}{n_i}\right)$. The square root of this product is stored in register 05. This value is then added to and subtracted from the contents of register 06, $\sum c_i x_i$, to form the desired confidence interval. The lower bound is displayed after the use of 2nd A' and the upper bound may be recalled by pressing R/S (table B-13).

An example will now be provided using this program to test for differences between population means for the fitness experiments.

C. APPLICATION OF THE TI 59 ANOVA PROGRAM

The null hypothesis, H_0, may be stated as - there is no difference in the cardiovascular fitness of those who do no exercise (Category I), those who run in excess of thirty miles per week (Category II), those whose exercise consists solely of lifting weights (Category III), those who lift weights and run in excess of twenty miles per week (Category IV), those who lift weights and run between ten and nineteen miles per week (Category V), and those who do not run or lift weights but participate in other activities such as basketball, racquetball or bicycling (Category VI). Table B-35 reflects the cardiovascular score for each of the thirty-six subjects tested by category as well as the mean for each category. The null hypothesis that there is no difference between these category means may be tested using the ANOVA program with each of the categories constituting a row for input.

After the program card has been read in, the ANOVA program is used by first calling program 06 of the statistics module to enter the data. After initialization with 2nd E', the data for each row are entered followed by A. For the cardiovascular scores (table B-35) the first row, Category I, would be entered as follows: 56.5, A; 58, A; 44.5, A; 33.5, A; 40, A. Once the row data have been entered 2nd B' is pressed to display the row mean, 48.4, followed by C' which displays the row MSD, 92.9. (The row mean must be recorded for use in posterior contrasts). The data are then entered in a similar fashion for the remaining five rows (Categories II through VI). Once all of the data have been entered, RST is pressed to return the calculator pointer to the ANOVA program. A is then pressed resulting in calculation of the ANOVA Table entries. The ANOVA entries are recalled with sequential presses of R/S. Table B-13 discussed earlier contains detailed instructions on the use of the ANOVA program. Table 5-1 depicts the ANOVA calculations for the cardiovascular scores of the six fitness test categories. The prob-value of .00027 is sufficiently small to cast doubt upon the null hypothesis that there is no difference in the cardiovascular fitness among the six categories tested.

As discussed previously, the prob-value tells how credible the null hypothesis is but it does not tell which categories differ given that there is cause to reject H_0. However, confidence intervals may be established for contrasts between the categories using Scheffe's formula which is programmed in the ANOVA routine [Ref. 13]. For the cardiovascular example, the cardiovascular fitness of the sedentary subjects (Category I) may be contrasted to the cardiovascular fitness of the runner (Category II) as a demonstration of the program. 2nd E' is pressed to initialize the contrast routine followed by c_i, x_i and n_i for each of the two rows. For Categories I and II the entries are:

1	R/S	48.4	R/S	6	R/S
-1	R/S	83.4	R/S	6	R/S

The appropriate F percentile is entered followed by A' to generate the desired confidence interval. To display a 95% confidence interval for the difference in cardiovascular fitness between Categories I and II an F percentile of 2.53 (where there are five degrees of freedom in the numerator and thirty degrees of freedom in the denominator) is used resulting in an interval from -65.5 to -41.4. Since 0 is not included in the interval it is reasonable to conclude that there is a difference in the cardiovascular fitness of the two categories. Table 5-2 contains the results of contrasting each of the six fitness categories. Only four contrasts result in the conclusion that there is a difference between the categories with 95% confidence: Category I - Category II (-65.5, -41.4); Category I - Category IV (-65.5, -4.4); Category II - Category III (.6, 61.8) and Category III - Category IV (-61.7, -6.0). These results indicate with 95% confidence that there is a difference in the cardiovascular fitness of those who run more than twenty miles per week (Categories II and IV) and those who do no running at all (Categories I and III), at least for those subjects examined.

The ANOVA program has also been applied to the strength and cardiovascular scores resulting from the experiment. Table B-36, Appendix B, reflects the strength scores of each of the thirty-six subjects by category. The ANOVA results are contained in Table 5-3. The prob-value of $.12 \times 10^{-8}$ indicates that the null hypothesis that there is no difference in the strength of members of the different categories should be rejected. Further analysis with posterior contrasts is necessary to see which categories differ. Table 5-4 contains the results of posterior contrasts with an F percentile of 2.53 for 95%

confidence with five and thirty degrees of freedom for the numerator and denominator respectively. Unlike the cardiovascular contrasts there are a number of differences in the strength results. Categories III and IV, which were composed of the most ardent weightlifters, differs from Categories I and III but not VI. These results are not surprising in that they confirm the hypothesis that different training programs result in different levels of fitness. In this instance where fitness is defined as strength, those who trained for strength were in fact stronger than those who did not. Again, without attempting inference to a larger population, these results may be used to gain insight into the probable differences that might be tested in a more appropriately designed experiment.

Table B-37, Appendix B depicts the endurance scores for the thirty-six subjects by category. Table 5-5 reflects the results of using the ANOVA program with the endurance scores as input. Once again, the prob-value of $.137 \times 10^{-6}$ indicates rejection of the null hypothesis (in this case that there is no difference in the upper body endurance of the members of the six different categories). The posterior contrasts (table 5-6) indicate that the weightlifters (Categories III, IV, V) differ from the non-weightlifters (Categories I, II, VI) in upper body endurance with 95% confidence. This also supports the hypothesis that different training programs result in different levels of fitness, subject again to the sampling restrictions previously discussed.

D. SUMMARY

While the results of the fitness experiment are interesting, the purpose of this analysis has been to demonstrate a statistical application of the TI 59 and not draw inference to a hitherto undefined population. The univariate program was used to calculate measures of central tendency and spread for the Category I Cardiovascular scores. The ANOVA program was used to test for differences in strength, endurance, and cardiovascular fitness among the six test categories. In both instances meaningful but guarded inferences were drawn from the test data.

The capabilities of the TI 59 in real world statistical analysis are impressive. The analyst can conduct sophisticated analysis of good-sized samples unconstrained by access to large computers. Using programs such as those demonstrated in this chapter the analyst need not even learn a programming language. All that is required to compute an F ratio or prob-value, for example, is the ability to follow simple users' instructions. While there are certainly samples whose size preclude the use of the TI 59, there are a pletheora of samples which can be analyzed more conveniently and just as efficiently at home or at the office using the TI 59.

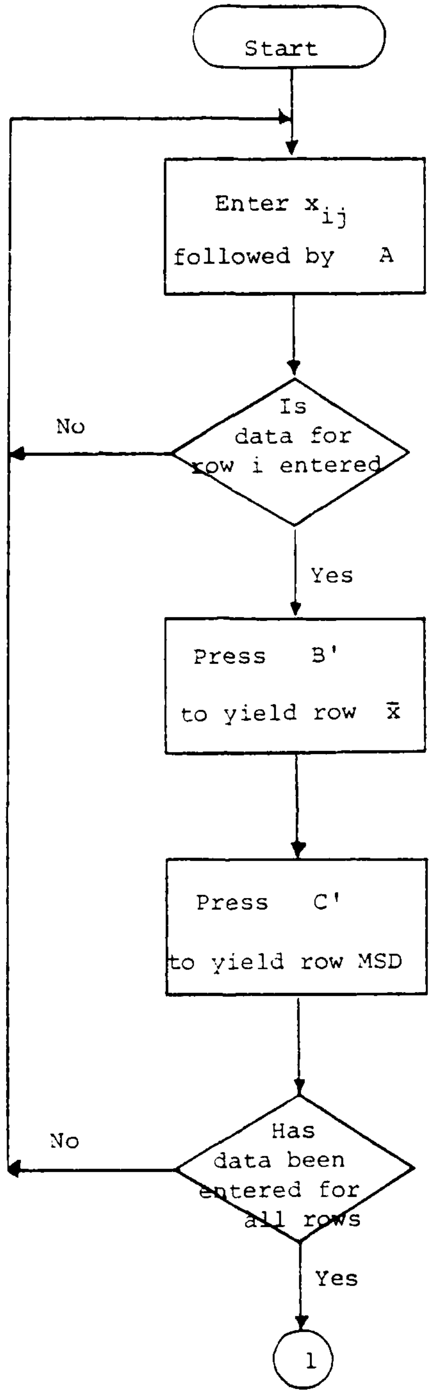

Start
Enter x_{ij}
followed by A
Is data for row i entered
No
Yes
Press B'
to yield row $\bar{x}$
Press C'
to yield row MSD
Has data been entered for all rows
No
Yes
1

Figure 5-1.1

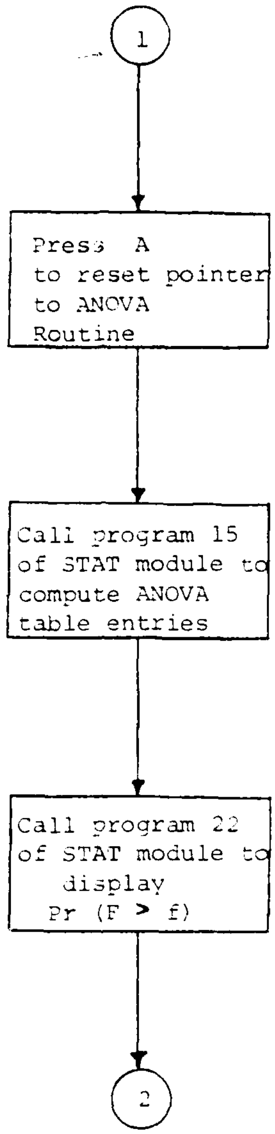

1
Press A
to reset pointer
to ANOVA
Routine
Call program 15
of STAT module to
compute ANOVA
table entries
Call program 22
of STAT module to
display
Pr (F > f)
2

Figure 5-1.2

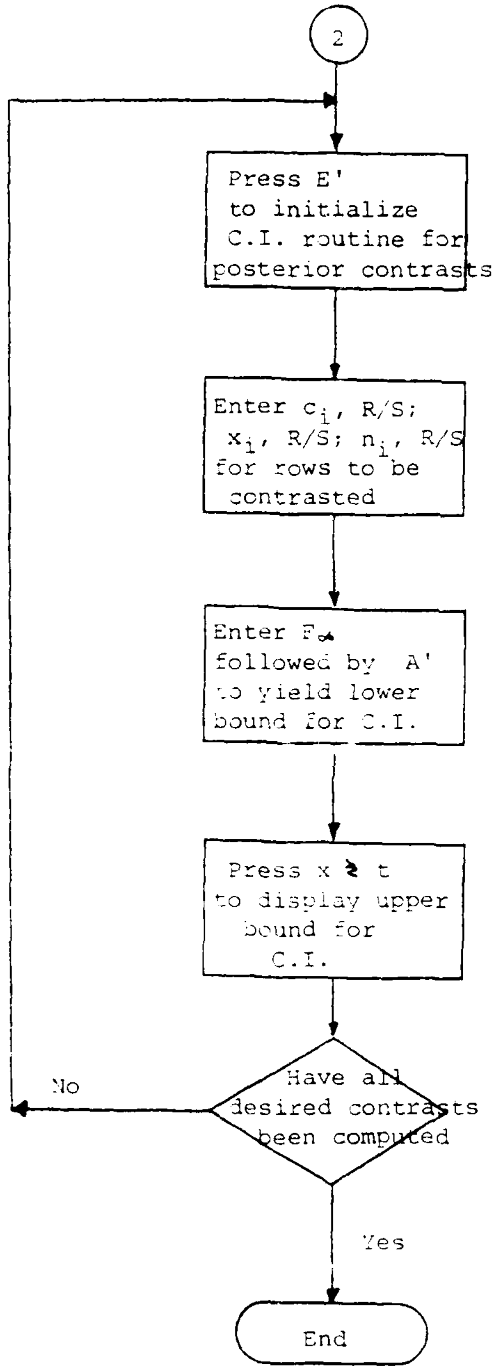

2
Press E' to initialize C.I. routine for posterior contrasts
Enter c_i, R/S; x_i, R/S; n_i, R/S for rows to be contrasted
Enter F_α followed by A' to yield lower bound for C.I.
Press x ⇄ t to display upper bound for C.I.
Have all desired contrasts been computed
No
Yes
End

Figure 5-1.7

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CARDIOVASCULAR ANOVA TABLE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE	F RATIO	PROB-VALUE
BETWEEN ROWS	$n \sum_{i=1}^{r} (\bar{x}_i - \bar{x})^2$ 1 7391.6	$(r - 1)$ 2 5.00	$nS_{\bar{x}}^2$ 3 1478.3	$\frac{nS_{\bar{x}}^2}{S_p^2}$	10 .00027
WITHIN ROWS	$\sum_{i}^{r} \sum_{j}^{n} (x_{ij} - \bar{x}_i)^2$ 4 6660.0	$r(n - 1)$ 5 30.0	S_p^2 6 222.0	9 6.659	
TOTAL	$\sum_{i} \sum_{j} (x_{ij} - \bar{x})^2$ 7 14,051.6	$(nr - 1)$ 8 35.0			

TABLE 5-1

CARDIOVASCULAR CONTRASTS

	1	2	3	4	5	6
1	—	-65.5 -41.4	-34.3 26.7	-65.5 - 4.4	-37.9 23.2	-53.1 8.1
2		—	.6 61.8	-30.6 30.6	- 2.9 58.2	-18.1 43.1
3			—	-61.7 - 6.0	-34.2 27.0	-49.2 11.9
4				—	- 2.9 58.2	-18.1 43.1
5					—	-45.7 15.5
6						—

TABLE 5-2

STRENGTH ANOVA TABLE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE	F RATIO	PROB-VALUE
BETWEEN ROWS	$n \sum_{i=1}^{r} (\bar{x}_i - \bar{x})^2$	$(r - 1)$	$nS_{\bar{x}}^2$	$\frac{nS_{\bar{x}}^2}{S_p^2}$	(10) .0000000012
	(1) 7.98	(2) 5.00	(3) 1.596		
WITHIN ROWS	$\sum_{i}^{r} \sum_{j}^{n} (x_{ij} - \bar{x}_i)^2$	$r(n - 1)$	S_p^2	(9) 23.90	
	(4) 1.99	(5) 30.00	(6) .0667		
TOTAL	$\sum_{i} \sum_{j} (x_{ij} - \bar{x})^2$	$(nr - 1)$			
	(7) 9.98	(8) 35.00			

TABLE 5-3

STRENGTH CONTRASTS

	1	2	3	4	5	6
1	———	- .67 .39	- 1.75 - .69	- 1.59 - .53	- 1.19 - .13	- .72 .34
2		———	- 1.61 - .55	- 1.45 - .39	- 1.05 .010	- .58 .48
3			———	- .37 .69	.03 1.09	.50 1.56
4				———	- .13 .93	.34 1.40
5					———	- .06 1.00
6						———

TABLE 5-4

ENDURANCE ANOVA TABLE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE	F RATIO	PROB-VALUE
BETWEEN ROWS	$n \sum_{i=1}^{r} (\bar{x}_i - \bar{x})^2$	$(r - 1)$	$nS_{\bar{x}}^2$	$\frac{nS_{\bar{x}}^2}{S_p^2}$	(10) $.137 \times 10^{-6}$
	(1) 6649.64	(2) 5.00	(3) 1329.92		
WITHIN ROWS	$\sum_{i}^{r} \sum_{j}^{n} (x_{ij} - \bar{x}_i)^2$	$r(n - 1)$	S_p^2	(9) 15.65	
	(4) 2549.41	(5) 30.00	(6) 84.98		
TOTAL	$\sum_{i} \sum_{j} (x_{ij} - \bar{x})^2$	$(nr - 1)$			
	(7) 9199.05	(8) 35.00			

TABLE 5-5

ENDURANCE CONTRASTS

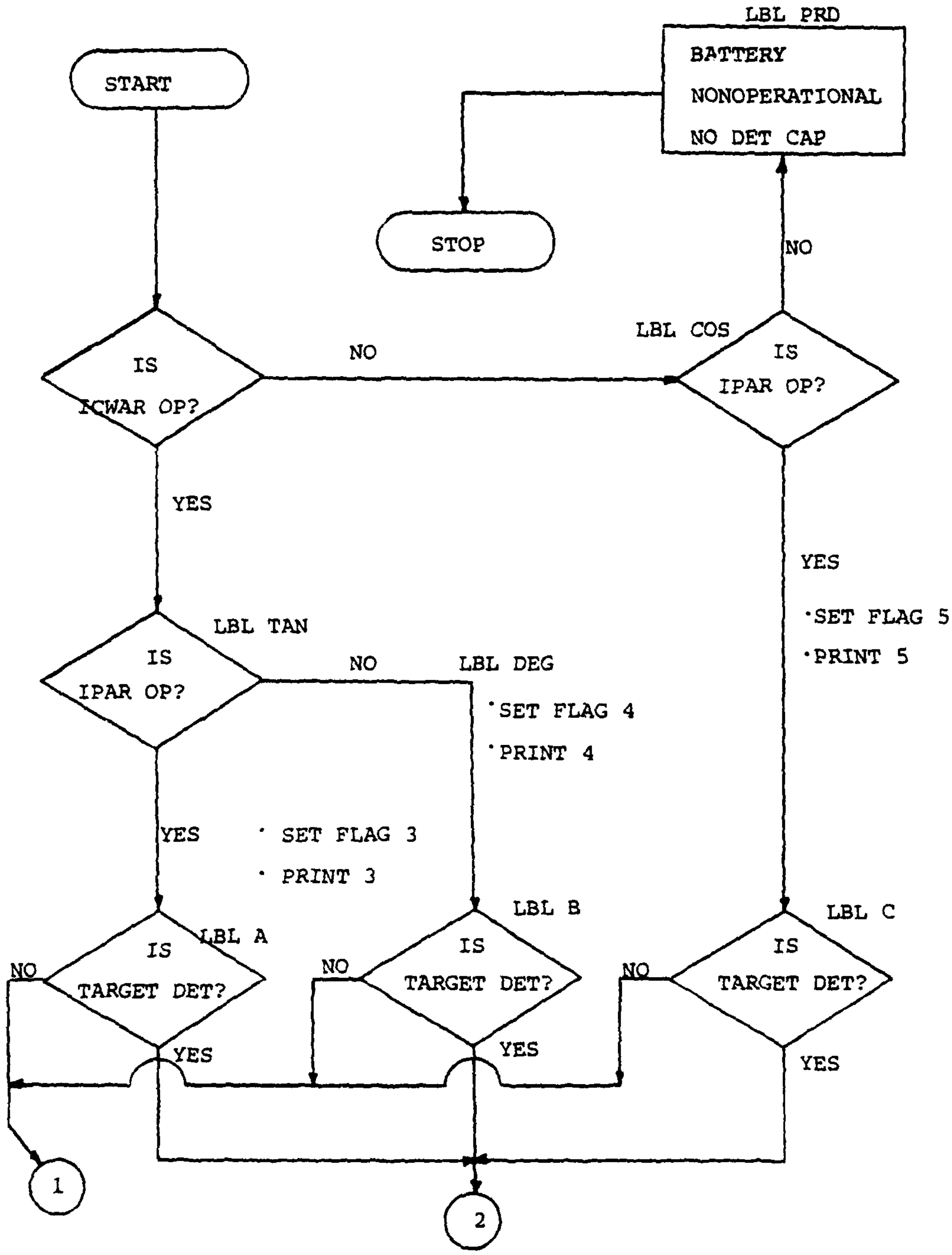
	1	2	3	4	5	6
1	———	-18.64 19.22	-50.14 -12.28	-48.06 -10.20	-37.99 - .14	-20.31 17.55
2		———	-50.43 -12.57	-48.35 -10.49	-38.29 - .43	-20.59 17.26
3			———	-16.85 21.00	- 6.79 31.06	10.90 48.76
4				———	- 8.87 28.99	8.82 46.68
5					———	- 1.24 36.61
6						———

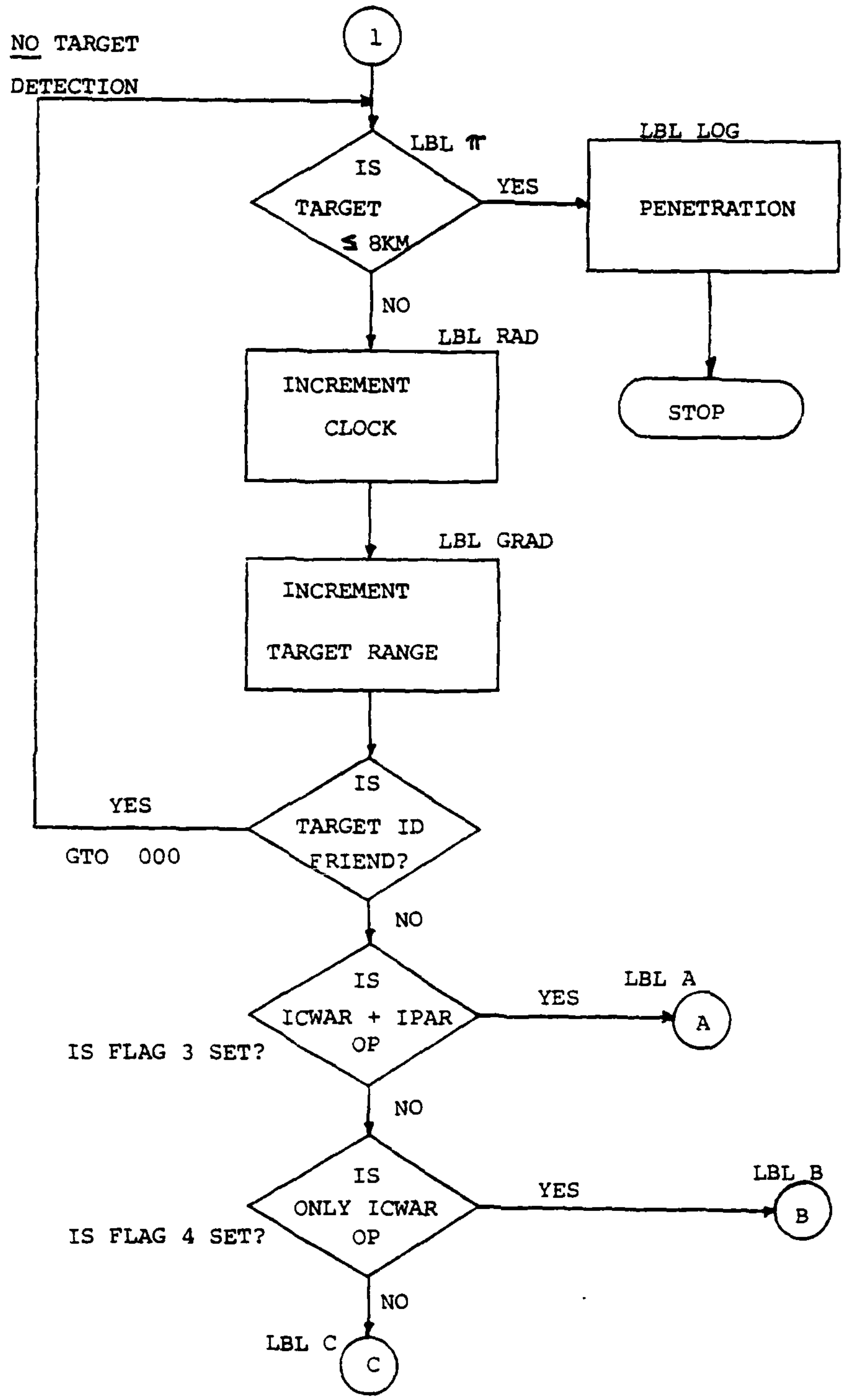
TABLE 5-6

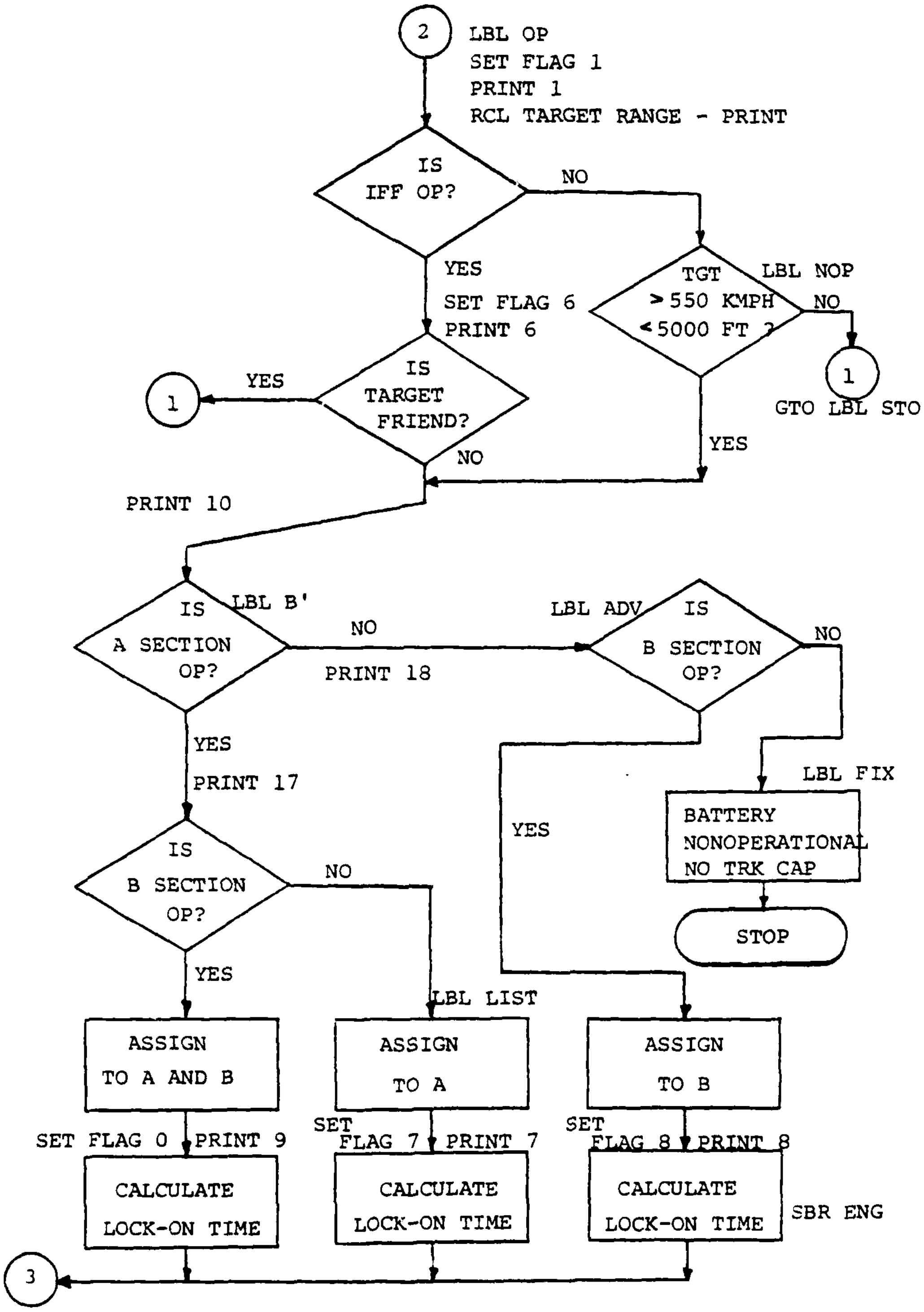
APPENDIX A

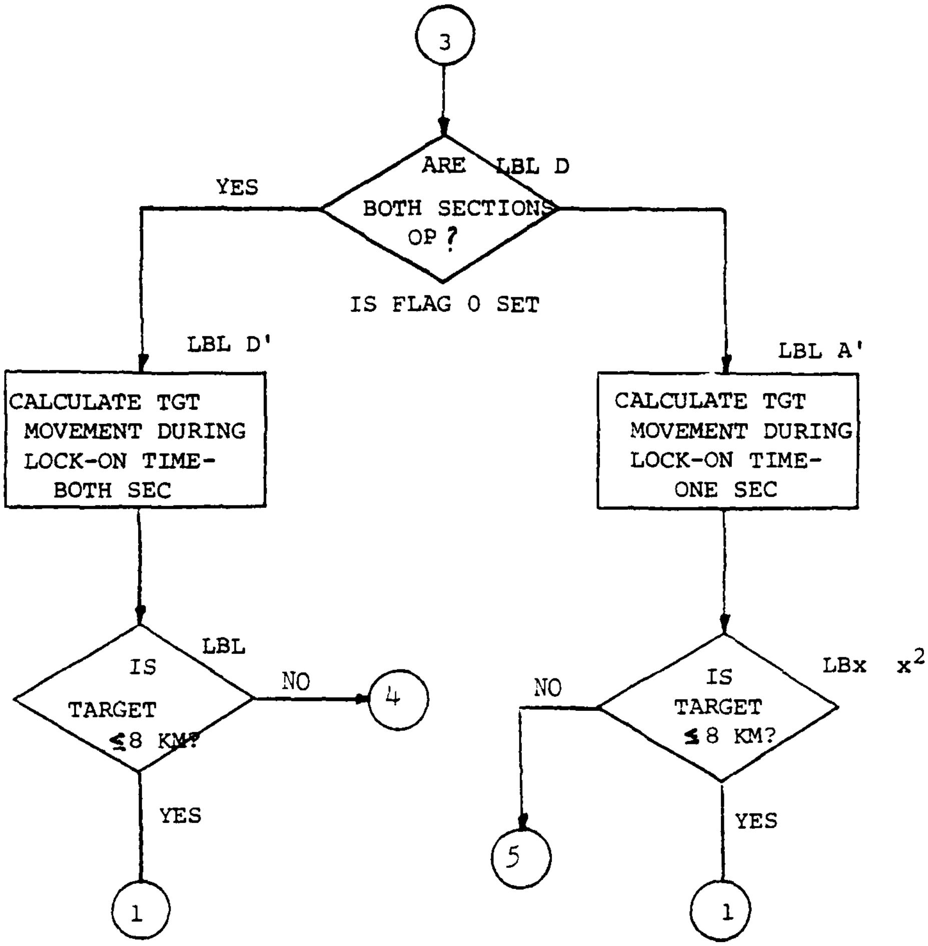
COMMENTS ON SELECTED LABELS

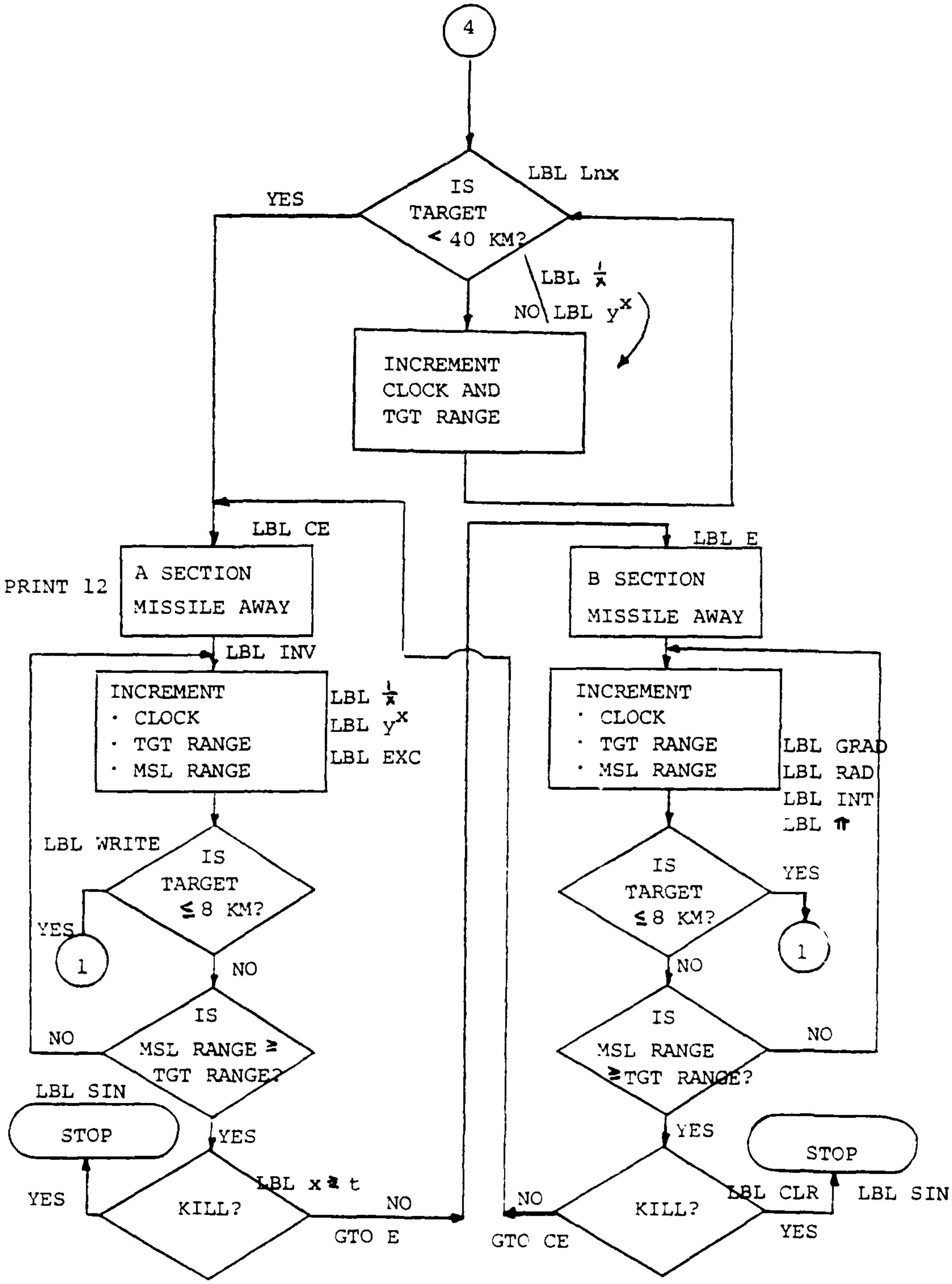
LABEL	COMMENT
A	Directs action to compute glimpse probability of detection for both ICWAR and IPAR
$\lvert X \rvert$	Computes glimpse probability of detection for ICWAR only based on target range
$\bar{X}$	Computes glimpse probability of detection for IPAR only based on target range
E and LnX	Determines if target is less than 40 KM from unit and directs processing accordingly.
D'	Calculates target range after elapse of target lock-on time.
(SBR) EXC and INT	Increments range of IHAWK missile after firing
FIX	Prints 24 (no firing capability)
DSZ	Prints 14 (cruise missile identified as friend)
NOP	Prints 66 (IFF is nonoperational)
OP	Prints 1 (target detected) at range (KM), begins engagement sequence
(SBR) RAD and y^x	Increments simulated air battle time clock (R_{19}).
(SBR) GRAD and $\frac{1}{x}$	Computes cruise missile rate of approach and increments target range (R_{00}).
(SBR) ENG	Random number generation - normal distribution
(SBR) P→R	Random number generator - uniform distribution
PRD	Prints 23 (no detection capability)
SIN	Prints "KILL" and range of target kill
LOG	Prints "PENETRATION"
(SBR) WRITE AND π	Prints "PENETRATION" if target is 8 KM or less from unit.

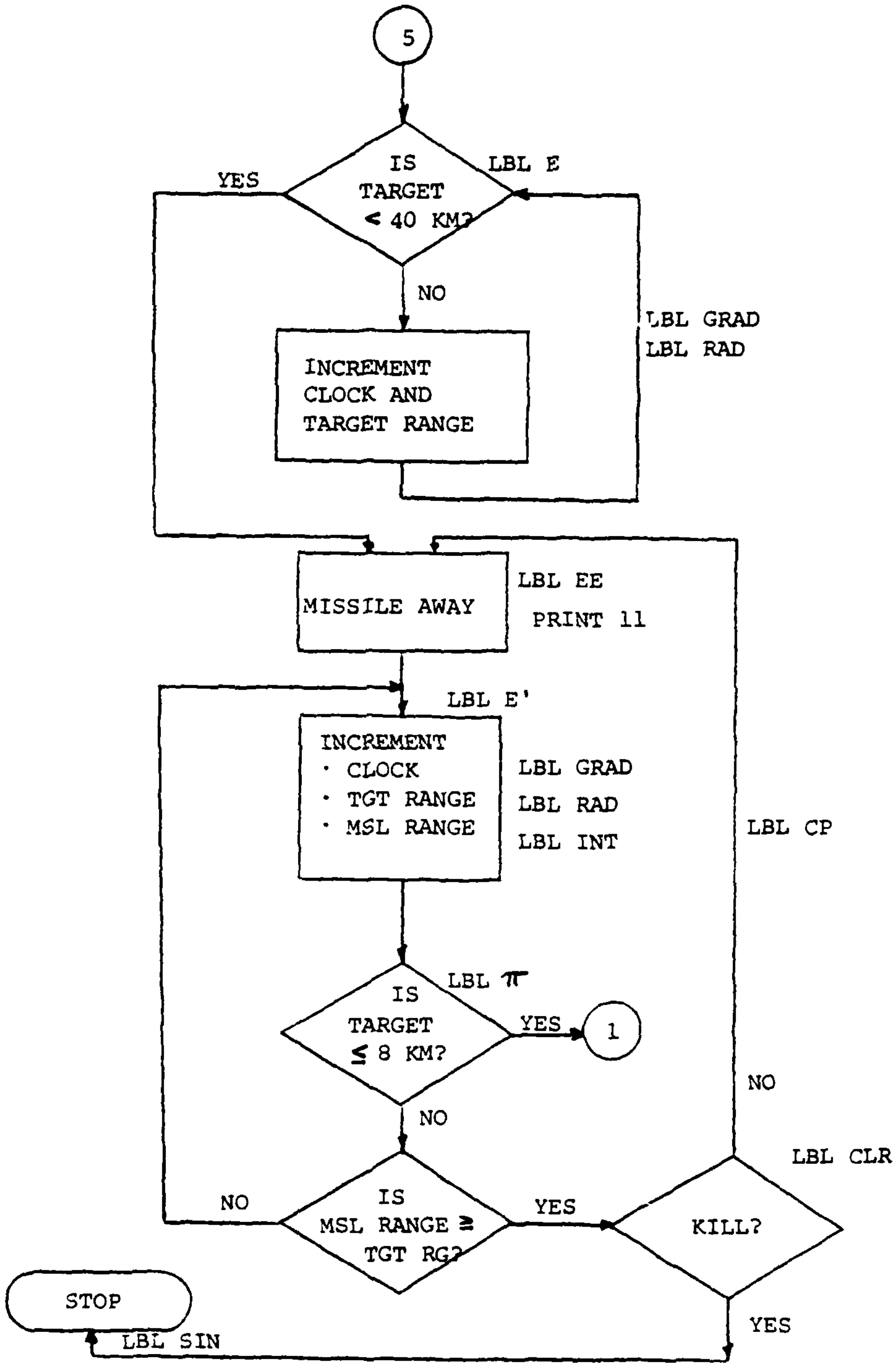

LBL PRD
BATTERY
NONOPERATIONAL
NO DET CAP
START
STOP
NO
LBL COS
IS
ICWAR OP?
NO
IS
IPAR OP?
YES
YES
·SET FLAG 5
·PRINT 5
LBL TAN
IS
IPAR OP?
NO
LBL DEG
·SET FLAG 4
·PRINT 4
YES
· SET FLAG 3
· PRINT 3
LBL A
IS
TARGET DET?
NO
YES
LBL B
IS
TARGET DET?
NO
YES
LBL C
IS
TARGET DET?
NO
YES
1
2


1
NO TARGET
DETECTION
LBL π
IS
TARGET
≤ 8KM
YES
LBL LOG
PENETRATION
STOP
NO
LBL RAD
INCREMENT
CLOCK
LBL GRAD
INCREMENT
TARGET RANGE
IS
TARGET ID
FRIEND?
YES
GTO 000
NO
IS
ICWAR + IPAR
OP
IS FLAG 3 SET?
YES
LBL A
A
NO
IS
ONLY ICWAR
OP
IS FLAG 4 SET?
YES
LBL B
B
NO
LBL C
C


2
LBL OP
SET FLAG 1
PRINT 1
RCL TARGET RANGE - PRINT
IS IFF OP?
NO
YES
SET FLAG 6
PRINT 6
TGT
>550 KMPH
<5000 FT ?
LBL NOP
NO
1
GTO LBL STO
IS TARGET FRIEND?
YES
1
NO
YES
PRINT 10
IS A SECTION OP?
LBL B'
NO
PRINT 18
LBL ADV
IS B SECTION OP?
NO
YES
PRINT 17
LBL FIX
BATTERY NONOPERATIONAL NO TRK CAP
STOP
YES
IS B SECTION OP?
NO
YES
LBL LIST
ASSIGN TO A AND B
ASSIGN TO A
ASSIGN TO B
SET FLAG 0
PRINT 9
SET FLAG 7
PRINT 7
SET FLAG 8
PRINT 8
CALCULATE LOCK-ON TIME
CALCULATE LOCK-ON TIME
CALCULATE LOCK-ON TIME
SBR ENG
3


3
ARE
BOTH SECTIONS
OP ?
LBL D
YES
IS FLAG 0 SET
LBL D'
CALCULATE TGT MOVEMENT DURING LOCK-ON TIME- BOTH SEC
LBL A'
CALCULATE TGT MOVEMENT DURING LOCK-ON TIME- ONE SEC
IS TARGET ≤8 KM?
LBL
NO
4
YES
1
IS TARGET ≤8 KM?
LBx x²
NO
5
YES
1


4
IS TARGET < 40 KM?
LBL Lnx
YES
NO
LBL 1/x
LBL y^x
INCREMENT CLOCK AND TGT RANGE
LBL CE
PRINT 12
A SECTION MISSILE AWAY
LBL INV
INCREMENT
· CLOCK
· TGT RANGE
· MSL RANGE
LBL 1/x
LBL y^x
LBL EXC
LBL WRITE
IS TARGET ≤ 8 KM?
YES
1
NO
IS MSL RANGE ≥ TGT RANGE?
NO
YES
LBL SIN
STOP
YES
KILL?
LBL x ⇄ t
NO
GTO E
LBL E
B SECTION MISSILE AWAY
INCREMENT
· CLOCK
· TGT RANGE
· MSL RANGE
LBL GRAD
LBL RAD
LBL INT
LBL π
IS TARGET ≤ 8 KM?
YES
1
NO
IS MSL RANGE ≥ TGT RANGE?
NO
YES
STOP
NO
KILL?
LBL CLR
LBL SIN
YES
GTO CE


5
IS TARGET < 40 KM?
LBL E
YES
NO
LBL GRAD
LBL RAD
INCREMENT CLOCK AND TARGET RANGE
MISSILE AWAY
LBL EE
PRINT 11
LBL E'
INCREMENT
· CLOCK
· TGT RANGE
· MSL RANGE
LBL GRAD
LBL RAD
LBL INT
LBL CP
LBL π
IS TARGET ≤ 8 KM?
YES
1
NO
NO
LBL CLR
IS MSL RANGE ≥ TGT RG?
NO
YES
KILL?
YES
STOP
LBL SIN

SIMULATION PROGRAM

000	71	SBR
001	89	π
002	71	SBR
003	80	GRD
004	71	SBR
005	70	RAD
006	87	IFF
007	02	02
008	00	00
009	00	00
010	87	IFF
011	03	03
012	11	A
013	87	IFF
014	04	04
015	12	B
016	87	IFF
017	05	05
018	13	C
019	71	SBR
020	37	P/R
021	93	.
022	06	6
023	05	5
024	32	X:T
025	77	GE
026	39	COS
027	61	GTO
028	30	TAN
029	76	LBL
030	39	COS
031	71	SBR
032	37	P/R
033	93	.
034	09	9
035	05	5
036	32	X:T
037	77	GE
038	49	PRD
039	86	STF
040	05	05
041	05	5
042	99	PRT
043	13	C
044	76	LBL
045	30	TAN
046	71	SBR
047	37	P/R
048	93	.
049	09	9
050	05	5
051	32	X:T
052	77	GE
053	60	DEG
054	86	STF
055	03	03
056	03	3
057	99	PRT
058	11	A
059	76	LBL
060	60	DEG
061	86	STF
062	04	04
063	04	4
064	99	PRT
065	12	B
066	76	LBL
067	69	OP
068	01	1
069	99	PRT
070	43	RCL
071	00	00
072	99	PRT
073	71	SBR
074	37	P/R
075	93	.
076	09	9
077	05	5
078	32	X:T
079	77	GE
080	68	NOP
081	06	6

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```
082   99  PRT
083   86  STF
084   06   06
085   71  SBR
086   37  P/R
087   93   .
088   09   9
089   08   8
090   32  X:T
091   77   GE
092   97  DSZ
093   01   1
094   00   0
095   99  PRT
096   61  GTO
097   17  B'
098   76  LBL
099   17  B'
100   71  SBR
101   37  P/R
102   93   .
103   07   7
104   05   5
105   32  X:T
106   77   GE
107   98  ADV
108   01   1
109   07   7
110   99  PRT
111   71  SBR
112   37  P/R
113   93   .
114   07   7
115   05   5
116   32  X:T
117   77   GE
118   90  LST
119   09   9
120   99  PRT
121   86  STF
122   00   00
123   71  SBR
124   57  ENG
125   32  X:T
126   42  STO
127   14   14
128   71  SBR
129   57  ENG
130   32  X:T
131   42  STO
132   08   08
133   18  C'
134   76  LBL
135   98  ADV
136   01   1
137   08   8
138   99  PRT
139   71  SBR
140   37  P/R
141   93   .
142   07   7
143   05   5
144   32  X:T
145   77   GE
146   58  FIX
147   08   8
148   99  PRT
149   86  STF
150   08   08
151   71  SBR
152   57  ENG
153   32  X:T
154   42  STO
155   08   08
156   18  C'
157   76  LBL
158   90  LST
159   07   7
160   99  PRT
161   86  STF
162   07   07
163   71  SBR
```

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```
164  57  ENG
165  32  X⇌T
166  42  STO
167  08   08
168  18  C'
169  76  LBL
170  42  STO
171  86  STF
172  02   02
173  01   1
174  05   5
175  99  PRT
176  61  GTO
177  00   00
178  00   00
179  76  LBL
180  18  C'
181  87  IFF
182  06   06
183  14   D
184  05   5
185  00   0
186  00   0
187  00   0
188  32  X⇌T
189  43  RCL
190  16   16
191  77   GE
192  42  STO
193  05   5
194  05   5
195  00   0
196  32  X⇌T
197  43  RCL
198  15   15
199  22  INV
200  77   GE
201  42  STO
202  76  LBL
203  14   D
204  87  IFF
205  00   0
206  19  D'
207  76  LBL
208  16  A'
209  53   (
210  43  RCL
211  08   08
212  55   ÷
213  03   3
214  85   +
215  93   .
216  05   5
217  54   )
218  59  INT
219  42  STO
220  04   04
221  76  LBL
222  43  RCL
223  71  SBR
224  80  GRD
225  71  SBR
226  70  RAD
227  97  DSZ
228  04   04
229  43  RCL
230  76  LBL
231  33  X²
232  71  SBR
233  89   π
234  76  LBL
235  15   E
236  04   4
237  00   0
238  32  X⇌T
239  43  RCL
240  00   00
241  22  INV
242  77   GE
243  52  EE
244  71  SBR
245  80  GRD
```

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246	71	SBR
247	70	RAD
248	61	GTO
249	15	E
250	76	LBL
251	52	EE
252	87	IFF
253	07	07
254	44	SUM
255	01	1
256	01	1
257	99	PRT
258	76	LBL
259	10	E'
260	71	SBR
261	80	GRD
262	71	SBR
263	70	RAD
264	71	SBR
265	59	INT
266	71	SBR
267	89	π
268	43	RCL
269	00	00
270	32	X:T
271	43	RCL
272	12	12
273	77	GE
274	25	CLR
275	61	GTO
276	10	E'
277	76	LBL
278	19	D'
279	53	(
280	43	RCL
281	14	14
282	55	÷
283	03	3
284	54	)
285	59	INT
286	42	STO
287	05	5
288	43	RCL
289	00	00
290	42	STO
291	17	17
292	43	RCL
293	19	19
294	42	STO
295	01	01
296	76	LBL
297	67	EQ
298	71	SBR
299	35	1/X
300	71	SBR
301	45	YX
302	97	DSZ
303	05	05
304	67	EQ
305	53	(
306	43	RCL
307	08	08
308	55	÷
309	03	3
310	85	+
311	93	.
312	05	5
313	54	)
314	59	INT
315	42	STO
316	04	04
317	76	LBL
318	88	DMS
319	71	SBR
320	80	GRD
321	71	SBR
322	70	RAD
323	97	DSZ
324	04	04
325	88	DMS
326	43	RCL
327	17	17

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```
328  32 X:T          369  17 E'
329  43 RCL          370  32 X:T
330  00  00          371  43 RCL
331  77  GE          372  13  13
332  33 X²           373  77  GE
333  76 LBL          374  32 X:T
334  34 √X           375  61 GTO
335  71 SBR          376  22 INV
336  96 WRT          377  76 LBL
337  76 LBL          378  32 X:T
338  23 LNX          379  71 SBR
339  04  4           380  37 P/R
340  00  0           381  93  .
341  32 X:T          382  07  7
342  43 RCL          383  05  5
343  17  17          384  32 X:T
344  22 INV          385  22 INV
345  77  GE          386  77  GE
346  24 CE           387  38 SIN
347  71 SBR          388  71 SBR
348  35 1/X          389  78 Σ+
349  71 SBR          390  61 GTO
350  45 YX           391  15  E
351  61 GTO          392  76 LBL
352  23 LNX          393  25 CLR
353  76 LBL          394  71 SBR
354  24 CE           395  37 P/R
355  01  1           396  93  .
356  02  2           397  07  7
357  99 PRT          398  05  5
358  76 LBL          399  32 X:T
359  22 INV          400  22 INV
360  71 SBR          401  77  GE
361  35 1/X          402  38 SIN
362  71 SBR          403  71 SBR
363  45 YX           404  29 CP
364  71 SBR          405  87 IFF
365  48 EXC          406  00  00
366  71 SBR          407  34 √X
367  96 WRT          408  61 GTO
368  43 RCL          409  15  E
```

QUALITY PRACTICABLE
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410	76	LBL
411	28	LOG
412	25	CLR
413	69	OP
414	00	00
415	03	3
416	03	3
417	69	OP
418	01	01
419	01	1
420	07	7
421	03	3
422	01	1
423	01	1
424	07	7
425	03	3
426	07	7
427	03	3
428	05	5
429	69	OP
430	02	02
431	01	1
432	03	3
433	03	3
434	07	7
435	02	2
436	04	4
437	03	3
438	02	2
439	03	3
440	01	1
441	69	OP
442	03	03
443	00	0
444	69	OP
445	04	04
446	69	OP
447	05	05
448	43	RCL
449	18	18
450	99	PRT
451	61	GTO
452	07	07
453	72	72
454	76	LBL
455	38	SIN
456	25	CLR
457	69	OP
458	00	00
459	69	OP
460	01	01
461	02	2
462	06	6
463	02	2
464	04	4
465	69	OP
466	02	02
467	02	2
468	07	7
469	02	2
470	07	7
471	00	0
472	00	0
473	00	0
474	00	0
475	00	0
476	00	0
477	69	OP
478	03	03
479	00	0
480	69	OP
481	04	04
482	69	OP
483	05	05
484	43	RCL
485	00	00
486	99	PRT
487	61	GTO
488	07	07
489	72	72
490	76	LBL
491	37	P/R

```
492  36 PGM
493  15  15
494  10 E'
495  36 PGM
496  15  15
497  71 SBR
498  88 DMS
499  32 X:T
500  92 RTN
501  76 LBL
502  49 PRD
503  02  2
504  03  3
505  99 PRT
506  61 GTO
507  04  04
508  10  10
509  76 LBL
510  11  A
511  71 SBR
512  50 I×I
513  42 STO
514  14  14
515  71 SBR
516  37 P/R
517  43 RCL
518  14  14
519  77  GE
520  69 OP
521  71 SBR
522  79  x̄
523  42 STO
524  14  14
525  71 SBR
526  37 P/R
527  43 RCL
528  14  14
529  77  GE
530  69 OP
531  61 GTO
532  00  00
533  00  0
534  76 LBL
535  12  B
536  08  8
537  00  0
538  00  0
539  00  0
540  32 X:T
541  43 RCL
542  16  16
543  77  GE
544  00  00
545  00  00
546  71 SBR
547  50 I×I
548  42 STO
549  14  14
550  71 SBR
551  37 P/R
552  43 RCL
553  14  14
554  77  GE
555  69 OP
556  61 GTO
557  00  00
558  00  00
559  76 LBL
560  13  C
561  43 RCL
562  16  16
563  32 X:T
564  05  5
565  00  0
566  00  0
567  00  0
568  77  GE
569  00  00
570  00  00
571  71 SBR
572  79  x̄
573  42 STO
```

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574	14	D
575	71	SBR
576	37	P/R
577	43	RCL
578	14	14
579	77	GE
580	69	OP
581	61	GTO
582	00	00
583	00	00
584	76	LBL
585	50	I×I
586	53	(
587	93	.
588	05	5
589	94	+/-
590	55	÷
591	06	6
592	05	5
593	65	×
594	43	RCL
595	00	00
596	85	+
597	01	1
598	54	)
599	92	RTN
600	76	LBL
601	89	π
602	43	RCL
603	00	00
604	32	X:T
605	08	8
606	77	GE
607	28	LOG
608	92	RTN
609	76	LBL
610	79	x̄
611	53	(
612	93	.
613	02	2
614	05	5
615	94	+/-
616	55	÷
617	06	6
618	05	5
619	65	×
620	43	RCL
621	00	00
622	85	+
623	01	1
624	54	)
625	92	RTN
626	76	LBL
627	59	INT
628	02	2
629	44	SUM
630	12	12
631	92	RTN
632	76	LBL
633	48	EXC
634	02	2
635	44	SUM
636	13	13
637	92	RTN
638	76	LBL
639	80	GRD
640	53	(
641	43	RCL
642	15	15
643	55	÷
644	01	1
645	02	2
646	00	0
647	00	0
648	54	)
649	22	INV
650	44	SUM
651	00	00
652	92	RTN
653	76	LBL
654	70	RAD
655	03	3

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656	44	SUM
657	19	19
658	92	RTN
659	76	LBL
660	68	NOP
661	06	6
662	06	6
663	99	PRT
664	61	GTO
665	17	B'
666	76	LBL
667	97	DSZ
668	01	1
669	04	4
670	99	PRT
671	86	STF
672	02	02
673	61	GTO
674	00	00
675	00	00
676	76	LBL
677	58	FIX
678	02	2
679	04	4
680	99	PRT
681	61	GTO
682	04	04
683	10	10
684	76	LBL
685	57	ENG
686	36	PGM
687	15	15
688	10	E'
689	43	RCL
690	10	10
691	36	PGM
692	15	15
693	11	A
694	43	RCL
695	11	11
696	36	PGM
697	15	E
698	12	B
699	36	PGM
700	15	15
701	18	C'
702	32	X:T
703	00	0
704	77	GE
705	57	ENG
706	92	RTN
707	76	LBL
708	29	CP
709	02	2
710	06	6
711	99	PRT
712	43	RCL
713	00	00
714	99	PRT
715	00	0
716	42	STO
717	12	12
718	42	STO
719	13	13
720	92	RTN
721	76	LBL
722	96	WRT
723	43	RCL
724	17	17
725	32	X:T
726	08	8
727	77	GE
728	28	LOG
729	92	RTN
730	76	LBL
731	78	Σ+
732	02	2
733	05	5
734	99	PRT
735	43	RCL
736	17	17
737	99	PRT

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738	00	0
739	42	STO
740	12	12
741	42	STO
742	13	13
743	92	RTN
744	76	LBL
745	35	1/X
746	53	(
747	43	RCL
748	15	15
749	55	÷
750	01	1
751	02	2
752	00	0
753	00	0
754	54	)
755	22	INV
756	44	SUM
757	17	17
758	92	RTN
759	76	LBL
760	45	Y^X
761	03	3
762	44	SUM
763	01	01
764	92	RTN
765	76	LBL
766	44	SUM
767	01	1
768	02	2
769	99	PRT
770	61	GTO
771	10	E'
772	00	0
773	22	INV
774	90	LST
775	98	ADV
776	98	ADV
777	05	5
778	00	0
779	42	STO
780	00	00
781	00	0
782	42	STO
783	12	12
784	42	STO
785	13	13
786	42	STO
787	19	19
788	32	X:T
789	01	1
790	22	INV
791	44	SUM
792	18	18
793	43	RCL
794	18	18
795	67	EQ
796	07	07
797	99	99
798	81	RST
799	91	R/S

APPENDIX B
INSTRUCTION SHEET

This is a physical fitness test.

I. WHAT WE ARE EXAMINING AND WHY

The following tests will look at the complex systems that make up the network of health and fitness. First we will test your upper body endurance and muscular strength. Next we will examine your cardiovascular health. This test is a component of a research project being conducted by graduate students of the Naval Postgraduate School.

II. MUSCULAR ENDURANCE AND STRENGTH

Muscular endurance is often synonymously and incorrectly used in place of muscular strength. Muscular strength is the ability of your muscular system to exert maximum force against an object or resistance all at once, your ability to exert a maximum force a single time. Muscular endurance relates to the ability to exert force, not necessarily maximal, over an extended time period. As with all the components of fitness, these two concepts are interrelated but distinctly different from each other. Each concerns itself with particular capacities of fitness.

III. CARDIOVASCULAR HEALTH

Objective: To measure your heart-rate response to exercise. This test will determine the relative efficiency of your heart and circulatory system. Your heart rate can be used to describe the fitness level of your body in three areas: how much oxygen you need, how much blood

TABLE B-1.1

your heart must pump to supply this need, and how hard your heart must work at this task. If your need for oxygen is not being fulfilled, your body is working in an inefficient manner. Consequently, more blood will have to be pumped through your circulatory system at a faster rate to get the oxygen to the muscles and organs that need it. The heart has the responsibility of satisfying your body's need for oxygen. It will have to beat more frequently to circulate the blood throughout your system. If your body works in an efficient manner, its need for oxygen is being fulfilled.

Thus cardiovascular health relates to the ability of the heart, lungs, and blood vessels to work in unison without strain. Regardless of what the task is, whether physical or mental, the cardiovascular system should be able to handle it. When you have high levels of cardiovascular health you perform with more efficiency and you are more effective at what you do.

TABLE B-1.2

QUESTIONNAIRE

THIS IS A PHYSICAL FITNESS TEST
READ THIS DOCUMENT CAREFULLY BEFORE THIS TEST BEGINS

(1) This test is completely voluntary! You may decline testing now if you wish. You may stop at any time during this test and decline further testing. You are under no obligation to complete this test.

(2) Before proceeding with this test, you should assure yourself and your tester that there have been no incidents in your medical history that would prohibit you from pursuing this testing. Your medical history is relevant to this physical fitness test.

(3) Please answer the following statements: YES or NO

(a) I have a heart related disease.

(b) I have high blood pressure.

(c) I often feel faint and suffer spells of dizziness.

(d) I have recently or in the past felt pain, heaviness or pressure in my chest.

(e) I have felt pain, heaviness or pressure in my chest when I walk uphill.

(f) My doctor has advised me not to engage in physical exercise or physical activity.

(4) I have read and fully understand this document.

DATE__________________ SIGNATURE______________________________

TABLE B-2

DATA SHEET

NAME_______________________________________

AGE____________ WEIGHT____________ DATE__________________

PHYSICAL ACTIVITY CATEGORY: I II III IV V VI

STRENGTH TEST:

Maximum Bench Press ______________

Maximum Curl ______________

ENDURANCE TEST:

Bench Press Repetitions With 100 Pounds

____

Curl Repetitions With 55 Pounds

____

CARDIOVASCULAR TEST: (Pulse Rate)

Resting ______________

Immediate Post Exercise ______________

30 Seconds Post Exercise ______________

60 Seconds Post Exercise ______________

120 Seconds Post Exercise ______________

TABLE B-3

	Codes																				Code Score
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
Resting Heart Rate	44	48	52	56	60	62	64	66	68	70	72	74	76	78	80	84	88	92	96	100	______
Posttest Heart Rate	80	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	148	152	156	______
Second Recovery Heart Rate	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	______
1 Minute Recovery Heart Rate	56	60	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	______
2 Minute Recovery Heart Rate	56	60	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	______
																				Total Code Score	______

TABLE B-4

CATEGORY I RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	29	190	56.5	1.26	24.1
2	33	155	58.0	1.32	12.9
3	36	170	58.0	.97	5.5
4	31	205	44.5	1.19	27.9
5	37	157	33.5	1.13	10.1
6	34	160	40.0	1.16	11.0

(1) See Table B-17 for derivation
(2) See Table B-18 for derivation
(3) See Table B-19 for derivation

TABLE B-5

CATEGORY II RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	33	167	91.5	1.47	22.0
2	34	195	96.5	1.41	28.9
3	35	180	55.0	1.11	12.2
4	33	160	93.5	1.44	13.6
5	28	127	82.0	1.34	6.5
6	30	158	82.0	1.11	6.6

(1) See Table B-20 for derivation
(2) See Table B-21 for derivation
(3) See Table B-22 for derivation

TABLE B-6

CATEGORY III RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	22	200	35.0	2.48	50.0
2	23	202	56.0	2.35	62.5
3	28	205	44.5	2.49	37.2
4	34	220	86.5	2.23	42.7
5	25	180	67.0	2.83	54.8
6	29	225	24.5	2.00	31.6

(1) See Table B-23 for derivation
(2) See Table B-24 for derivation
(3) See Table B-25 for derivation

TABLE B-7

CATEGORY IV RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	28	200	96.5	2.30	47.5
2	31	180	79.0	2.67	49.0
3	32	165	85.0	2.00	43.7
4	32	160	79.0	2.19	47.2
5	19	240	89.5	1.85	34.3
6	26	180	71.5	2.39	44.6

(1) See Table B-26 for derivation
(2) See Table B-27 for derivation
(3) See Table B-28 for derivation

TABLE B-8

CATEGORY V RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	30	165	39.5	2.03	25.5
2	24	175	55.0	2.43	54.1
3	19	185	47.0	1.86	47.0
4	34	179	77.5	1.73	33.5
5	35	205	59.5	1.15	22.0
6	30	120	56.5	1.75	23.8

(1) See Table B-29 for derivation
(2) See Table B-30 for derivation
(3) See Table B-31 for derivation

TABLE B-9

CATEGORY VI RESULTS

SUBJECT	AGE	WEIGHT	CARDIOVASCULAR SCORE (1)	STRENGTH SCORE (2)	ENDURANCE SCORE (3)
1	27	180	61.0	1.42	23.1
2	32	125	47.5	1.56	17.4
3	31	170	65.5	1.26	14.7
4	31	170	85.0	1.41	15.3
5	33	175	86.5	1.34	11.4
6	30	205	30.0	1.15	17.9

(1) See Table B-32 for derivation
(2) See Table B-33 for derivation
(3) See Table B-34 for derivation

TABLE B-10

Univariate User Instructions				
Step	Procedure	Enter	Press	Display
1.	Initialize		2nd E'	31
2.	Enter data	x_i	A	i
	Repeat for each x_i			
3.	Recall Statistics		2nd $\bar{x}$	$\bar{x}$
			INV 2nd $\bar{x}$	s
			2nd OP 11	MSD
			RCL 12	x_{min}
			RCL 13	x_{max}
			RCL 14	MIDVAL
			RCL 15	range
			2nd A'	MAD
			RCL 03	n
4.	Recall data entered in			
	Step 2 if desired.		RCL 31	x_1
			RCL 32	x_2
			RCL 31 + i -1	x_i

TABLE B-11

UNIVARIATE PROGRAM

000	76	LBL	041	18	C'
001	10	E'	042	22	INV
002	47	CMS	043	77	GE
003	22	INV	044	00	00
004	86	STF	045	57	57
005	00	00	046	43	RCL
006	03	3	047	13	13
007	01	1	048	32	X:T
008	42	STO	049	43	RCL
009	30	30	050	18	18
010	91	R/S	051	77	GE
011	76	LBL	052	00	00
012	11	A	053	62	62
013	42	STO	054	61	GTO
014	18	18	055	00	00
015	72	ST*	056	64	64
016	30	30	057	42	STO
017	01	1	058	12	12
018	44	SUM	059	61	GTO
019	30	30	060	00	00
020	87	IFF	061	64	64
021	00	00	062	42	STO
022	65	×	063	13	13
023	43	RCL	064	53	(
024	18	18	065	53	(
025	42	STO	066	43	RCL
026	12	12	067	12	12
027	42	STO	068	85	+
028	13	13	069	43	RCL
029	78	Σ+	070	13	13
030	86	STF	071	54	)
031	00	00	072	55	÷
032	43	RCL	073	02	2
033	03	03	074	54	)
034	91	R/S	075	42	STO
035	76	LBL	076	14	14
036	65	×	077	53	(
037	43	RCL	078	43	RCL
038	12	12	079	13	13
039	32	X:T	080	75	-
040	43	RCL	081	43	RCL

TABLE B-12.1

082	12	B
083	54	)
084	42	STO
085	15	15
086	43	RCL
087	18	18
088	61	GTO
089	00	00
090	29	29
091	76	LBL
092	16	A'
093	79	x̄
094	94	+/-
095	42	STO
096	16	16
097	43	RCL
098	03	03
099	42	STO
100	07	07
101	03	3
102	01	1
103	42	STO
104	20	20
105	00	0
106	42	STO
107	19	19
108	76	LBL
109	44	SUM
110	53	(
111	73	RC*
112	20	20
113	85	+
114	43	RCL
115	16	16
116	54	)
117	50	I×I
118	44	SUM
119	19	19
120	01	1
121	44	SUM
122	20	20
124	07	7
125	44	SUM
126	43	43
127	19	D'
128	55	÷
129	43	RCL
130	03	03
131	95	=
132	91	R/S
133	76	LBL
134	14	D
135	03	3
136	01	1
137	42	STO
138	30	30
139	91	R/S
140	00	0
141	00	0
142	00	0
143	00	0
144	00	0
145	00	0
146	00	0
147	00	0
148	00	0
149	00	0
150	00	0
151	00	0
152	00	0
153	00	0
154	00	0
155	00	0
156	00	0
157	00	0
158	00	0
159	00	0
160	00	0
161	00	0
162	00	0
163	00	0

TABLE B-12.2

ANOVA USER INSTRUCTIONS				
Step	Procedure	Enter	Press	Display
1	Select Program 06		2nd Pgm 06	
2	Initialize data base		2nd E'	0
3	Enter data for each row	x_{ij}	A	r_i
4	Reset pointer if more than 29 data entries are made		D	31
5	Calculate $\bar{x}$ for current row		2nd B'	x_i
6	Calculate MSD for current row		2nd C'	MSD_i
7	Return to step 3 to enter next row data			
8	Return pointer to ANOVA program		RST	
9	Calculate ANOVA table entries Note: the numbers in parentheses in the display column correspond to the numbered blocks in the ANOVA table (table 4-4)		A	ss_r (1)
			R/S	r-1 (2)
			R/S	MSS_r (3)
			R/S	SS_u (4)
			R/S	r(n-1) (5)
			R/S	MSS_u (6)
			R/S	SS_t (7)
			R/S	(nr-1) (8)
			R/S	F ratio (9)
			R/S	Prob-value (10)

TABLE B-13.1

ANOVA USER INSTRUCTIONS				
Step	Procedure	Enter	Press	Display
	Confidence Intervals for Contrasts			
10	Initialize		E'	0
11	Enter contrast data	C_i	R/S	C_i
	Repeat for each row i	x_i	R/S	x_i
		n_i	R/S	n_i
12	Enter F percentile with degrees of freedom r-1, r(n-1)	F	A' $x \rightleftarrows t$	1 μ

TABLE B-13.2

ANOVA PROGRAM

```
000  76 LBL
001  11  A
002  36 PGM
003  15  15
004  11  A
005  42 STO
006  00  00
007  43 RCL
008  08  08
009  91 R/S
010  43 RCL
011  14  14
012  91 R/S
013  43 RCL
014  15  15
015  91 R/S
016  43 RCL
017  13  13
018  91 R/S
019  43 RCL
020  16  16
021  91 R/S
022  43 RCL
023  17  17
024  42 STO
025  29  29
026  91 R/S
027  43 RCL
028  12  12
029  91 R/S
030  43 RCL
031  09  09
032  75  -
033  01  1
034  95  =
035  91 R/S
036  43 RCL
037  00  00
038  91 R/S
039  43 RCL
040  14  14
041  36 PGM
042  22  22
043  11  A
044  43 RCL
045  16  16
046  36 PGM
047  22  22
048  12  B
049  43 RCL
050  00  00
051  36 PGM
052  22  22
053  13  C
054  92 RTN
055  76 LBL
056  10 E'
057  36 PGM
058  01  01
059  71 SBR
060  25 CLR
061  76 LBL
062  33 X²
063  91 R/S
```

TABLE B-14.1

064	42	STO
065	01	01
066	91	R/S
067	42	STO
068	02	02
069	91	R/S
070	35	1/X
071	65	×
072	43	RCL
073	01	01
074	33	X²
075	95	=
076	44	SUM
077	03	03
078	43	RCL
079	01	01
080	65	×
081	43	RCL
082	02	02
083	95	=
084	44	SUM
085	06	06
086	01	1
087	44	SUM
088	04	04
089	43	RCL
090	04	04
091	61	GTO
092	33	X²
093	76	LBL
094	16	A'
095	65	×
096	43	RCL
097	14	14
098	65	×
099	43	RCL
100	29	29
101	65	×
102	43	RCL
103	03	03
104	95	=
105	34	ΓX
106	42	STO
107	05	05
108	85	+
109	43	RCL
110	06	06
111	95	=
112	32	X⇌T
113	43	RCL
114	06	06
115	75	-
116	43	RCL
117	05	05
118	95	=
119	92	RTN
120	00	0
121	00	0
122	00	0
123	00	0
124	00	0
125	00	0

TABLE B-14.2

ANOVA TABLE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE	F RATIO	PROB-VALUE
BETWEEN ROWS	$n \sum_{i=1}^{r} (\bar{x}_i - \bar{x})^2$	$(r - 1)$	$nS_{\bar{x}}^2$	$\dfrac{nS_{\bar{x}}^2}{S_p^2}$	10
	1	2	3		
WITHIN ROWS	$\sum_{i}^{r} \sum_{j}^{n} (x_{ij} - \bar{x}_i)^2$	$r(n - 1)$	S_p^2	9	
	4	5	6		
TOTAL	$\sum_{i} \sum_{j} (x_{ij} - \bar{x})^2$	$(nr - 1)$			
	7	8			

TABLE B-15

FITNESS EXAMPLE

CATEGORY	SUBJECT 1	2	3	4	5	6	
I (Sedentary)	x_{I1}						$\bar{x}_I$
II (Runners)			x_{II3}				$\bar{x}_{II}$
III (Weightlifters)					x_{III5}		$\bar{x}_{III}$

$$\bar{x}_i = \frac{1}{n_i} \Sigma x_{ij}$$ n_i = the number of subjects in Category i

$$\bar{\bar{x}} = \frac{1}{r} \sum_{i=1}^{r} \bar{x}_i$$ r = the number of categories

TABLE B-16

CATEGORY I - CARDIOVASCULAR SCORES

	Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 - Heart Rate	66	114	108	90	90	56.5
Pipes Score	13	11.5	9	11.5	11.5	
Subject #2 - Heart Rate	72	114	96	90	84	58
Pipes Score	10	11.5	12	11.5	13	
Subject #3 - Heart Rate	66	126	102	90	78	58
Pipes Score	13	8.5	10.5	11.5	14.5	
Subject #4 - Heart Rate	78	120	108	102	96	44.5
Pipes Score	7	10	9	8.5	10	
Subject #5 - Heart Rate	84	132	114	108	108	33.5
Pipes Score	5	7	7.5	7	7	
Subject #6 - Heart Rate	78	126	114	102	102	40
Pipes Score	7	8.5	7.5	8.5	8.5	

TABLE B-17

CATEGORY I - ADJUSTED STRENGTH SCORES

$$S_{1i} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{11} = \frac{150 + 90}{190} = 1.26$$

$$S_{12} = \frac{130 + 75}{155} = 1.32$$

$$S_{13} = \frac{90 + 75}{170} = .97$$

$$S_{14} = \frac{160 + 85}{205} = 1.19$$

$$S_{15} = \frac{105 + 70}{157} = 1.13$$

$$S_{16} = \frac{110 + 75}{160} = 1.16$$

$$S_{1\bar{x}} = \frac{124 + 78}{173} = 1.17$$

TABLE B-18

CATEGORY I - ADJUSTED ENDURANCE SCORES

$$E_{1i} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{array}{c}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{array}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{array}{c}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{array}\right)$$

$$E_{11} = \left(\frac{100}{190}\right)(31) + \left(\frac{55}{190}\right)(27) = 24.1$$

$$E_{12} = \left(\frac{100}{155}\right)(9) + \left(\frac{55}{155}\right)(20) = 12.9$$

$$E_{13} = \left(\frac{100}{170}\right)(0) + \left(\frac{55}{170}\right)(17) = 5.5$$

$$E_{14} = \left(\frac{100}{205}\right)(32) + \left(\frac{55}{205}\right)(46) = 27.9$$

$$E_{15} = \left(\frac{100}{157}\right)(2) + \left(\frac{55}{157}\right)(25) = 10.1$$

$$E_{16} = \left(\frac{100}{160}\right)(5) + \left(\frac{55}{160}\right)(23) = 11.0$$

$$E_{1\bar{x}} = \left(\frac{100}{173}\right)(13) + \left(\frac{55}{173}\right)(26) = 15.7$$

TABLE B-19

CATEGORY II - CARDIOVASCULAR SCORES

		Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 -	Heart Rate	60	90	60	60	60	91.5
	Pipes Score	16	17.5	20	19	19	
Subject #2 -	Heart Rate	48	90	60	48	48	96.5
	Pipes Score	19	17.5	20	20	20	
Subject #3 -	Heart Rate	72	120	102	96	78	55.0
	Pipes Score	10	10	10.5	10	14.5	
Subject #4 -	Heart Rate	54	90	66	60	54	93.5
	Pipes Score	17.5	17.5	19.5	19	20	
Subject #5 -	Heart Rate	66	90	72	72	66	82
	Pipes Score	13	17.5	18	16	17.5	
Subject #6 -	Heart Rate	60	108	72	66	66	82
	Pipes Score	16	13	18	17.5	17.5	

TABLE B-20

CATEGORY II - ADJUSTED STRENGTH SCORES

$$S_{2i} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{21} = \frac{160 + 85}{167} = 1.47$$

$$S_{22} = \frac{170 + 105}{195} = 1.41$$

$$S_{23} = \frac{130 + 70}{180} = 1.11$$

$$S_{24} = \frac{150 + 80}{160} = 1.44$$

$$S_{25} = \frac{110 + 60}{127} = 1.34$$

$$S_{26} = \frac{100 + 75}{158} = 1.11$$

$$S_{2\bar{x}} = \frac{137 + 79}{165} = 1.31$$

TABLE B-21

CATEGORY II - ADJUSTED ENDURANCE SCORES

$$E_{2i} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{matrix}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{matrix}\right)$$

$$E_{21} = \left(\frac{100}{167}\right)(23) + \left(\frac{55}{167}\right)(25) = 22.0$$

$$E_{22} = \left(\frac{100}{195}\right)(31) + \left(\frac{55}{195}\right)(46) = 28.9$$

$$E_{23} = \left(\frac{100}{180}\right)(11) + \left(\frac{55}{180}\right)(20) = 12.2$$

$$E_{24} = \left(\frac{100}{160}\right)(14) + \left(\frac{55}{160}\right)(15) = 13.6$$

$$E_{25} = \left(\frac{100}{127}\right)(5) + \left(\frac{55}{127}\right)(6) = 6.5$$

$$E_{26} = \left(\frac{100}{158}\right)(4) + \left(\frac{55}{158}\right)(12) = 6.6$$

$$E_{2\bar{x}} = \left(\frac{100}{165}\right)(15) + \left(\frac{55}{165}\right)(21) = 16.1$$

TABLE B-22

CATEGORY III - CARDIOVASCULAR SCORES

	Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 - Heart Rate	90	120	120	102	108	35
Pipes Score	3.5	10	6	8.5	7	
Subject #2 - Heart Rate	78	114	114	96	96	56
Pipes Score	7	11.5	7.5	10	10	
Subject #3 - Heart Rate	78	120	114	96	96	44.5
Pipes Score	7	10	7.5	10	10	
Subject #4 - Heart Rate	54	90	84	66	60	86.5
Pipes Score	17.5	17.5	15	17.5	19	
Subject #5 - Heart Rate	72	114	78	78	78	67
Pipes Score	10	11.5	16.5	14.5	14.5	
Subject #6 - Heart Rate	84	138	132	120	108	24.5
Pipes Score	5	5.5	3	4	7	

TABLE B-23

CATEGORY III - ADJUSTED STRENGTH SCORES

$$S_{3i} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{31} = \frac{330 + 165}{200} = 2.48$$

$$S_{32} = \frac{320 + 155}{202} = 2.35$$

$$S_{33} = \frac{375 + 135}{205} = 2.49$$

$$S_{34} = \frac{305 + 185}{220} = 2.23$$

$$S_{35} = \frac{320 + 190}{180} = 2.83$$

$$S_{36} = \frac{320 + 130}{225} = 2.00$$

$$S_{3\bar{x}} = \frac{328 + 160}{205} = 2.38$$

TABLE B-24

CATEGORY III - ADJUSTED ENDURANCE SCORES

$$E_{3i} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{array}{c}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{array}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{array}{c}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{array}\right)$$

$$E_{31} = \left(\frac{100}{200}\right)(67) + \left(\frac{55}{200}\right)(60) = 50.0$$

$$E_{32} = \left(\frac{100}{202}\right)(85) + \left(\frac{55}{202}\right)(75) = 62.5$$

$$E_{33} = \left(\frac{100}{205}\right)(57) + \left(\frac{55}{205}\right)(35) = 37.2$$

$$E_{34} = \left(\frac{100}{220}\right)(61) + \left(\frac{55}{220}\right)(60) = 42.7$$

$$E_{35} = \left(\frac{100}{180}\right)(70) + \left(\frac{55}{180}\right)(52) = 54.8$$

$$E_{36} = \left(\frac{100}{225}\right)(54) + \left(\frac{55}{225}\right)(31) = 31.6$$

$$E_{3\bar{x}} = \left(\frac{100}{205}\right)(66) + \left(\frac{55}{205}\right)(52) = 46.1$$

TABLE B-25

CATEGORY IV - CARDIOVASCULAR SCORES

	Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 - Heart Rate	48	84	66	60	54	96.5
Pipes Score	19	19	19.5	19	20	
Subject #2 - Heart Rate	66	108	72	66	66	79
Pipes Score	13	13	18	17.5	17.5	
Subject #3 - Heart Rate	60	102	72	66	60	85
Pipes Score	16	14.5	18	17.5	19	
Subject #4 - Heart Rate	66	108	72	66	66	79
Pipes Score	13	13	18	17.5	17.5	
Subject #5 - Heart Rate	60	90	72	60	60	89.5
Pipes Score	16	17.5	18	19	19	
Subject #6 - Heart Rate	72	108	78	72	72	71.5
Pipes Score	10	13	16.5	16	16	

TABLE B-26

CATEGORY IV - ADJUSTED STRENGTH SCORES

$$S_{4i} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{41} = \frac{290 + 170}{200} = 2.30$$

$$S_{42} = \frac{305 + 175}{180} = 2.67$$

$$S_{43} = \frac{205 + 125}{165} = 2.00$$

$$S_{44} = \frac{230 + 120}{160} = 2.19$$

$$S_{45} = \frac{310 + 135}{240} = 1.85$$

$$S_{46} = \frac{275 + 155}{180} = 2.39$$

$$S_{4\bar{x}} = \frac{270 + 147}{188} = 2.22$$

TABLE B-27

CATEGORY IV - ADJUSTED ENDURANCE SCORES

$$E_{41} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{matrix}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{matrix}\right)$$

$$E_{41} = \left(\frac{100}{200}\right)(52) + \left(\frac{55}{200}\right)(78) = 47.5$$

$$E_{42} = \left(\frac{100}{180}\right)(53) + \left(\frac{55}{180}\right)(64) = 49.0$$

$$E_{43} = \left(\frac{100}{165}\right)(44) + \left(\frac{55}{165}\right)(51) = 43.7$$

$$E_{44} = \left(\frac{100}{160}\right)(37) + \left(\frac{55}{160}\right)(70) = 47.2$$

$$E_{45} = \left(\frac{100}{240}\right)(55) + \left(\frac{55}{240}\right)(50) = 34.3$$

$$E_{46} = \left(\frac{100}{180}\right)(50) + \left(\frac{55}{180}\right)(55) = 44.6$$

$$E_{4\bar{x}} = \left(\frac{100}{188}\right)(49) + \left(\frac{55}{188}\right)(61) = 43.9$$

TABLE B-28

CATEGORY V - CARDIOVASCULAR SCORES

	Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 - Heart Rate	84	132	108	102	96	
Pipes Score	5	7	9	8.5	10	39.5
Subject #2 - Heart Rate	72	114	102	90	90	
Pipes Score	10	11.5	10.5	11.5	11.5	55
Subject #3 - Heart Rate	90	126	96	90	90	
Pipes Score	3.5	8.5	12	11.5	11.5	47
Subject #4 - Heart Rate	66	102	78	72	66	
Pipes Score	13	14.5	16.5	16	17.5	77.5
Subject #5 - Heart Rate	66	126	102	84	78	
Pipes Score	13	8.5	10.5	13	14.5	59.5
Subject #6 - Heart Rate	78	120	90	90	78	
Pipes Score	7	10	13.5	11.5	14.5	56.5

TABLE B-29

CATEGORY V - ADJUSTED STRENGTH SCORES

$$S_{5i} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{51} = \frac{220 + 115}{165} = 2.03$$

$$S_{52} = \frac{265 + 160}{175} = 2.43$$

$$S_{53} = \frac{220 + 125}{185} = 1.86$$

$$S_{54} = \frac{200 + 110}{179} = 1.73$$

$$S_{55} = \frac{170 + 65}{205} = 1.15$$

$$S_{56} = \frac{140 + 70}{120} = 1.75$$

$$S_{5\bar{x}} = \frac{203 + 108}{172} = 1.81$$

TABLE B-30

CATEGORY V - ADJUSTED ENDURANCE SCORES

$$E_{5i} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{matrix}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{matrix}\right)$$

$$E_{51} = \left(\frac{100}{165}\right)(30) + \left(\frac{55}{165}\right)(22) = 25.5$$

$$E_{52} = \left(\frac{100}{175}\right)(37) + \left(\frac{55}{175}\right)(105) = 54.1$$

$$E_{53} = \left(\frac{100}{185}\right)(54) + \left(\frac{55}{185}\right)(60) = 47.0$$

$$E_{54} = \left(\frac{100}{179}\right)(33) + \left(\frac{55}{179}\right)(49) = 33.5$$

$$E_{55} = \left(\frac{100}{205}\right)(28) + \left(\frac{55}{205}\right)(31) = 22.0$$

$$E_{56} = \left(\frac{100}{120}\right)(22) + \left(\frac{55}{120}\right)(12) = 23.8$$

$$E_{5\bar{x}} = \left(\frac{100}{172}\right)(34) + \left(\frac{55}{172}\right)(47) = 34.8$$

TABLE B-31

CATEGORY VI - CARDIOVASCULAR SCORES

		Resting	Immediate	30 Sec	60 Sec	120 Sec	Score
Subject #1 -	Heart Rate	72	114	96	84	78	61
	Pipes Score	10	11.5	12	13	14.5	
Subject #2 -	Heart Rate	78	126	108	90	90	47.5
	Pipes Score	7	8.5	9	11.5	11.5	
Subject #3 -	Heart Rate	72	114	90	78	72	65.5
	Pipes Score	10	11.5	13.5	14.5	16	
Subject #4 -	Heart Rate	60	102	72	66	60	85
	Pipes Score	16	14.5	18	17.5	19	
Subject #5 -	Heart Rate	54	90	78	66	66	86.5
	Pipes Score	17.5	17.5	16.5	17.5	17.5	
Subject #6 -	Heart Rate	42	102	90	84	60	80
	Pipes Score	20	14.5	13.5	13	19	

TABLE B-32

CATEGORY VI - ADJUSTED STRENGTH SCORES

$$S_{61} = \frac{\text{BENCH PRESS + CURL}}{\text{BODY WEIGHT}}$$

$$S_{61} = \frac{155 + 100}{180} = 1.42$$

$$S_{62} = \frac{120 + 75}{125} = 1.56$$

$$S_{63} = \frac{130 + 85}{170} = 1.26$$

$$S_{64} = \frac{135 + 105}{170} = 1.41$$

$$S_{65} = \frac{145 + 90}{175} = 1.34$$

$$S_{66} = \frac{145 + 90}{205} = 1.15$$

$$S_{6\bar{x}} = \frac{138 + 91}{171} = 1.34$$

TABLE B-33

CATEGORY VI - ADJUSTED ENDURANCE SCORES

$$E_{6i} = \left(\frac{100}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF BENCH PRESS}\\ \text{REPETITIONS}\end{matrix}\right) + \left(\frac{55}{\text{BODY WT}}\right)\left(\begin{matrix}\text{NUMBER OF CURL}\\ \text{REPETITIONS}\end{matrix}\right)$$

$$E_{61} = \left(\frac{100}{180}\right)(25) + \left(\frac{55}{180}\right)(30) = 23.1$$

$$E_{62} = \left(\frac{100}{125}\right)(14) + \left(\frac{55}{125}\right)(14) = 17.4$$

$$E_{63} = \left(\frac{100}{170}\right)(14) + \left(\frac{55}{170}\right)(20) = 14.7$$

$$E_{64} = \left(\frac{100}{170}\right)(15) + \left(\frac{55}{170}\right)(20) = 15.3$$

$$E_{65} = \left(\frac{100}{175}\right)(10) + \left(\frac{55}{175}\right)(18) = 11.4$$

$$E_{66} = \left(\frac{100}{205}\right)(23) + \left(\frac{55}{205}\right)(25) = 17.9$$

$$E_{6\bar{x}} = \left(\frac{100}{171}\right)(17) + \left(\frac{55}{171}\right)(21) = 16.8$$

TABLE B-34

CARDIOVASCULAR SCORES

CATEGORY	SUBJECT #1	#2	#3	#4	#5	#6	$\bar{x}$
I	56.5	58.0	58.0	44.5	33.5	40.0	48.4
II	91.5	96.5	55.0	93.5	82.0	82.0	83.4
III	35.0	56.0	44.0	86.5	67.0	24.5	52.2
IV	96.5	79.0	85.0	79.0	89.5	71.5	83.4
V	39.5	55.0	47.0	77.5	59.5	56.5	55.8
VI	61.0	47.5	65.5	85.0	86.5	80.0	70.9

TABLE B-35

STRENGTH SCORES

CATEGORY \ SUBJECT	#1	#2	#3	#4	#5	#6	$\bar{x}$
I	1.26	1.32	.97	1.19	1.13	1.16	1.17
II	1.47	1.41	1.11	1.44	1.34	1.11	1.31
III	2.48	2.35	2.49	2.23	2.83	2.00	2.39
IV	2.30	2.67	2.00	2.19	1.85	2.39	2.23
V	2.03	2.43	1.86	1.73	1.15	1.75	1.83
VI	1.42	1.56	1.26	1.41	1.34	1.15	1.36

TABLE B-36

ENDURANCE SCORES

CATEGORY	SUBJECT #1	#2	#3	#4	#5	#6	$\bar{x}$
I	24.1	12.9	5.5	27.9	10.1	11.0	15.25
II	22.0	28.9	12.2	13.6	6.5	6.6	14.96
III	50.0	62.5	37.2	42.7	54.8	31.6	46.46
IV	47.5	49.0	43.7	47.2	34.3	44.6	44.38
V	25.5	54.1	47.0	33.5	22.0	23.8	34.32
VI	23.1	17.4	14.7	15.3	11.4	17.9	16.63

TABLE B-37

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